THE BOOK WAS DRENCHED

TEXT LITE WITHIN THE BOOK ONLY

Text Fly

PHASES OF MODERN SCIENCE

PHASES

OF

MODERN SCIENCE

Published in connexion with the Science Exhibit arranged by a Committee of the Royal Society in the Pavilion of His Majesty's Government at the British Empire Exhibition, 1925.

Sold by A. and F. Denny, Ltd., 163A, Strand,
. . . London, W.C.2. . . .

COAT-OF-ARMS OF THE ROYAL SOCIETY.

The armorial bearings granted to the Royal Society by Charles II are described in the second Charter in the following words :—

" These following blazons of honour, that is to say, in the dexter corner of a silver shield our three Lions of England, and for crest a helm adorned with a crown studded with florets, surmounted by an eagle of proper colour holding in one foot a shield charged with our lions ; Supporters, two white hounds gorged with crowns ; to be borne, exhibited, and possessed for ever . . . . ." (Translation.)

CONTENTS.

GUIDE TO THE EXHIBITS IN THE SCIENCE GALLERIES.

PREFACE.

THE book constitutes a second edition of the Handbook to the Royal Society's exhibit in the Pavilion of His Majesty's Government at the British Empire Exhibition in 1924. Certain of the articles included in the earlier volume have been omitted, while others related more closely to the exhibits in their altered arrangement have been added. The original articles have been revised by the authors.

The first section contains the revised series of articles by well-known authors, and is intended to give some indication of the state of Science at the time of the Exhibition; the second section is the Handbook to the exhibits, numbered to correspond with cards displayed on the benches and in the cases.

The British Empire Exhibition Committee of the Royal Society desire to express their indebtedness to the authors who have contributed articles and to the various bodies and persons who have kindly given permission to incorporate in these articles material appearing in their publications.

RADIATION.

By Sir Oliver Lodge, F.R.S.

Part I.—A General Survey.

It is now generally accepted that the material universe is composed of atoms, and most people now know (though no one knew a quarter of a century ago) that the atoms are built up of electric units, and that the different atoms, the atoms of the chemical elements, only differ in the number and arrangement of the electric particles. It is also known that these electric particles are of two kinds, and two only: the positive kind, which is now usually called a proton; and the negative kind, which for some thirty years has been called an electron. Some idea of the size of these particles has also been obtained. They are the smallest things at present known; and they are the basis of all electrical manifestation. In fact, they constitute what we call electricity.

The first and most obvious property of these particles is difference of sign, so that they tend to attract and to neutralise each other, and thus in combination to form a neutral (that is a non-electrified) atom. One of each constitutes the simplest atom possible, which is the familiar atom of hydrogen. It may be supposed that two of each would constitute the next atom, the atom of helium; and so on up to 92, constituting ninety-two chemical elements, which differ in no other way than in the number and distribution of these ultimate particles. The word "ultimate" may be premature, and may have to be modified; for at one time we used to speak of "the ultimate atom" meaning the atom of matter. We now know that the atom of matter is a complex thing, built up of two simple units, which separately are the positive and

the negative electric charges. The atom of matter has a constitution therefore—a structure which is being ascertained. Whether the electric units have a structure, and what that structure is, is at present unknown. We must deal with them as if they were the ultimate units—at any rate, for a time.

The way in which the units are arranged inside the atom may be the subject of legitimate difference of opinion. But that electricity consists of these two units, in enormous numbers, and that groupings of them constitute the atoms, no one doubts. The atoms arrange themselves in molecules according to certain laws, which are studied in chemistry: and thus all material bodies are constructed. In other words, everything we see or handle, and all the worlds in space, are composed of two kinds of electricity—that is, of two apparently fundamental things with opposite properties—and at first sight of nothing else.

But the two kinds of electricity attract each other; each unit is very highly electrified, and the attraction between them is very forcible. The attraction of an electron for a proton,—say, 4 diameters apart—is comparable to the weight of a couple of pounds. The first question which arises is, what keeps them from clashing into each other? We know of another set of bodies which attract each other but do not clash, namely, the planets and satellites in the heavens. The earth does not fall into the sun, though it is attracted by a tremendous force, comparable to a thousand million million tons; the moon does not fall upon the earth. What keeps them apart is their motion. Pull or attraction is satisfied when the smaller body revolves round the other, in a definite orbit at a definite pace; and the rate of motion is adapted to the orbit, or the orbit is adapted to the rate of motion. If the moon were nearer it would have to revolve faster: the farther a planet is off, the slower it goes.

Something the same sort seems to be happening inside the atom: the attracting particles may revolve round each other and thus keep at a fixed distance apart. That is what by most people is believed to happen: though there is another way of keeping bodies apart, analogous to springs or elastic cushions; and this more static method of contemplation is favoured by some, though springs require much more explanation and are less satisfactory as a separating cause, and certainly less simple, than mere motion. Moreover, the analogy of the heavenly bodies is not to be despised; and it is tempting to apply the laws of astronomy to the electric particles inside the atom.

Indeed, it turns out that the analogy of the solar system is remarkably borne out by facts. The proton and the electron, though electrically equal and opposite, are not equal in all respects: the proton is more than 1,800 times as massive or heavy as an electron. The earth is 80 times as massive or heavy as the moon. Hence, just as the earth stays fairly still while the moon revolves round it, so in the atom of hydrogen the proton can stay fairly still, as a centre, while the electron revolves round it.

In the atoms of the other and heavier chemical atoms this is further accentuated. The weight of the nucleus has long been known under the name " atomic weight " and this atomic weight is many thousands of times greater, even up to nearly half a million times greater, than the weight of any of the satellite electrons. Consequently, the analogy of a nearly stationary central body like the sun, and a number of much lighter planets circulating round it, is a very natural and satisfactory one. This is the theory of the constitution of matter which at present holds the field—or rather it is the outline and first beginning of that theory. We may well pause to express wonder and admiration at the simplicity of the material elements of the cosmos, and at the elaboration of all the beauty and majesty and complexity of the material universe out of two fundamental units.

But is there nothing else? Still keeping strictly to physics (and not touching on the other things which we know to exist but which transcend physics, such as life and mind and consciousness), is there no third thing in the physical scheme other than the two electrical units? If not, it may well be wondered, not so much how the attracting units keep apart, as how it is that they attract each other at all: and still more how it is that we have learnt anything about either them or their attraction.

There certainly is a third thing; and, without the slightest controversy, that third thing is radiation—radiation and all that it implies. The most usual view of radiation is that it consists of waves in a connecting medium, commonly called " the ether," and that this same unique and only ether is responsible for gravitative attraction, for electric and magnetic attractions, and for cohesion: that is, for all the forces which tend to bring bodies together, while motion tends to keep them apart. This, however, is a fact which may be expressed by different people in different ways: there are some who do not care to use the term " ether," and are not sure of the nature of the waves, but no one can doubt the fact of radiation.

Again we make appeal to the heavenly bodies. All the large bodies are furiously radiating; they are what we call "hot," and it is through their radiation that we are aware of their existence. They are extruding or leaking energy at a tremendous rate, and in the eye we have a receiving instrument which responds to that energy; so that although some of these hot bodies or suns are many million of million miles away, they still appeal to us, and give us information about themselves, through the fraction of their radiation which falls upon our optical receiving instruments. This is a kind of wireless telegraphy to which the human race has always been accustomed.

The very fact that bodies separated in space attract each other shows that there must be some intervening mechanism or substance to account for what are called their fields of force, and this is clinched by finding that the intervening space is full of radiation. It is through and by means of radiation that we are acquainted with all the other worlds in the universe: it is by the same channel that we are aware of all the objects in the neighbourhood—all that we do not touch: it is by means of radiation that we see the landscape and all the beauties of Nature. Our sense of music depends upon the vibrations of the air; while everyone agrees that the sense of colour, and of vision generally, is wholly dependent upon radiation. We apprehend matter through our sense of touch, our muscular sense: we apprehend radiation through our optical sense. Thus, the physical universe contains not only protons and electrons but also a connecting link, which for brevity is best called the ether; while radiation is most conveniently thought of as a perturbation, or vibration or tremor or quiver, in the ether, excited somehow by a corresponding movement in the protons or electrons themselves.

THE SOURCE OF RADIATION.

Returning once more to the larger heavenly bodies—the sun and other stars—it is obvious that they are radiating; but it is not obvious why they are pouring out their energy like that, nor is it obvious whence they derive that energy. So long as we study pure astronomy on the large scale there is no explanation. It might be that occasionally there was a clash in the heavens—two bodies colliding, and that this would account for some of the energy. Such collision may indeed, possibly, account for the occasional appearance of a new star—that

is, for an extra and unexpected splash of radiation. But collisions are infrequent, and ideas of that sort are quite insufficient to explain the steady glow of the sun and the other stars. There must be some source of energy in the units of which they are composed—that is, in the atoms. We must return to the atom and see if we can find it.

At first sight the idea of the atom that we have so far formulated contains no clue. A central nucleus with electrons revolving round it appears as a simple, quiescent, regular system, from which radiation is no more to be expected than from the earth and moon. If you want to excite ripples on a calm sheet of water you must make a splash—say, by throwing a stone into it; the ripples will then spread out from the centre of disturbance. If you want to make a bell vibrate, it is no use swinging it gently; you must hit it. To excite radiation, some kind of sudden motion, something analogous to a blow or a collision or a fall, is necessary—something like a projectile striking a target, some sudden or violent disturbance. Otherwise, things will go on placidly, like the steady motion of the planets, or like well-oiled machinery. If the electrons in the atoms kept to their respective orbits there would be no radiation. As a matter of fact, atoms do radiate when treated vigorously; in a vacuum tube it is possible to fling electrons against a target, and they thus produce X-rays. That is the simplest way of producing radiation—the way that is best understood—and it gave us a hint. Prof. N. Bohr, of Copenhagen, had the genius to surmise that although a hydrogen atom consisted of a single electron revolving in an orbit round a proton, yet that there was more than one orbit in which it might revolve, and that occasionally it dropped from one possible orbit to another. This would be regarded as a sudden unexplained catastrophic movement, analogous, perhaps, to the striking of an electron against a target, except that there was no target. Hence the process is not quite easy to imagine, and there is no analogy to it in the heavenly bodies. The planet Mars does not suddenly drop to the orbit of the earth. Nor have we any reason to suppose that only a selection of planetary orbits are possible. If there is any reason for Bode's law it is unknown. There is something that goes on in the atom for which we have no large scale analogy; but if only a selection of orbits round an atomic nucleus is possible, and if a drop from one possible orbit to another did occur, there would certainly be radiation of energy, because the drop would generate a surplus of energy, which would have to be emitted somehow.

Assuming that atomic radiation is thus generated, the kind of radiation could be calculated. Given a regular succession of possible orbits, a certain kind of radiation would be produced by dropping from any one to any other. A small drop would give comparatively long-wave or low frequency radiation: a big drop into a region of high speed would give high-frequency short-wave radiation. Each drop would give a definite wave-length, and these wave-lengths could be analysed by the spectroscope—that is, by the lines in the spectrum; for, in the spectrum, each line, or each position, corresponds to a definite wave-length. Bohr made the necessary calculation. The actual radiation was analysed and was found exactly to correspond with Bohr's theory. Moreover, the theory enabled other wave-lengths to be predicted, and these were looked for, and in due course found. So far as the atom of hydrogen is concerned, the dropping from one of the alternative orbits to another accounts for every line and every series of lines which hydrogen is able to emit; and not only accounts for them roughly or approximately but also with accurate and, indeed, astronomical precision. Nor are only the relative positions of the lines given; the absolute wave-length can be calculated when we know the electrical attraction between the electron and the proton.

Since that great discovery the theory has been applied to other atoms, and, although naturally it becomes more complex, the growing completeness with which most of the phenomena are explained has caused it to be almost universally accepted. The cause of radiation is not so fully understood as we hope to understand it in the next ten or twenty years; but it is undoubtedly due to sudden movements—sudden readjustments of the constituent electrons in an atom.

Thus the physical universe consists not only of electrons and protons in regular grouping and steady orbital movement, but also in sudden changes or rearrangements of that movement, and consequent excitation or perturbation of the universal connecting medium in which the movements occur.

The physical universe consists, therefore, of three things, however they be constituted and further explained:—

(1) The positive electric charge.
(2) The negative electric charge.
(3) The radiation due to sudden movements and rearrangements among those charged particles.

It is by this third or apparently supplementary, subsidiary or accidental, consequence of the spasmodic behaviour of the

other two that we know anything about them and about the other worlds in space which they constitute. The radiation of the sun and stars is explicable and has to be explained in terms of these atomic convulsions.

The atoms and worlds are like each other in many respects. Looking at the midnight sky, we see discontinuity, portions of matter scattered about with large spaces between: looking with the mind's eye at the atom, we see the same thing. All the objects we touch and handle are constructed after somewhat the same fashion as the midnight sky; except that whereas the astronomical bodies are controlled wholly by gravitation, and their large scale motion gives them no radiating power of their own, the atoms are controlled mainly by electrical forces. Their particles are in close touch with the ether, and they are subject to perturbations, which in a more or less known and explicable manner disturb the medium, as a struck bell disturbs the air, so that they emit the radiation that we call light. The astronomy of the atom is like the astronomy of the heavens, but is more fundamental and contains more surprising facts.

The simplicity with which results are secured in Nature is marvellous. The rotation of the earth, with its atmosphere, gives us day and night and the beauties of dawn and sunset. The earth's revolution round the sun gives us the year, and a slight tilt in the earth's axis of rotation gives us all the beauty of the seasons. So, also, the fact that in an atom there is more than one possible orbit for each electron, and that occasionally electrons are able to jump from one to another, gives us the whole of what we study under the immense science of radiation, and through our sense of vision gives us colour, luminosity, apprehension of distance, and perception of the multiplicity of worlds far away in the depths of space.

PART II.—THE SPECTRUM OF RADIATION.

Now let us begin to consider in detail what we have learnt about this great branch of science. A certain kind of ether wave has been employed by the human race, and animals too, from time immemorial, since in the eye we possess a sensitive receiving instrument which has enabled us to detect ether waves of extremely short wave-length; but only within the last century have we known that the physical basis of light was a succession of waves in the ether, of a length which could be measured, and that the wealth and variety of colours

were due to different wave-lengths or frequencies of vibration. It is well known that waves which produce the sensation of red are the longest of those that can be called light, that those which stimulate the sense of violet are the shortest, and that the waves exciting the sense of green are intermediate. Not that the waves have any colour attached to them; colour seems to be wholly an interpretation of the mind. Physically there is nothing but different frequencies of vibration, over a definite range of wave-length. We can analyse any beam of light into its constituents; for when the waves are bent out of their course by a prism, the different wave-lengths are differently bent, and accordingly are sorted out in regular gradation, in what is called a spectrum—"continuous" if waves of all lengths are present, a "discontinuous" or "line spectrum" if there is only a clearly marked and definite selection of wave-lengths to be separated out.

The visible spectrum is but a small portion of the whole: beyond its violet end is a great range of still more rapid vibrations which are called "ultra-violet"; and beyond that again come the X-rays emitted by vacuum-tubes, and the gamma-rays emitted by radium. All these affect certain chemicals and therefore are able to be photographed. The ultra-violet spectrum extends a very long way. At the opposite or infra-red end of the spectrum are waves which do not excite the sense of sight, and cannot easily be photographed, but they are able to generate heat when their energy is absorbed by matter. By these waves the earth is kept warm. Far below them again we have the waves discovered by Hertz, which may vary in length from a few centimetres to several miles: these are used in radio-telegraphy. There appears to be no limit to either the length or the smallness of ether waves; and the remarkable thing is that they all travel at precisely the same pace. We have every reason to believe that the wave-velocity in free ether—that is, in space empty of matter—is always identically the same, namely, 300,000 kilometres or 186,000 miles a second.

Matter only obstructs ether waves: it may absorb some and transmit others, and the selective absorption thus exercised depends on the nature of the matter. Thus, a line spectrum may consist either of bright lines, when only a selection of waves is emitted; or it may consist of dark lines when a selection from an otherwise continuous series of waves is absorbed, by passing through a partially transparent medium. This is called an "absorption spectrum," and all matter is partially absorbent.

A transparent laminated structure is often able to reflect a little light from every one of its concealed internal surfaces or strata: and if the strata are equidistant, one below another with perfect regularity, then, in the light reflected by each, one single wave-length (corresponding to the distance of the layers slantingly apart) can be reinforced by co-operation; thus giving a remarkably pure colour at any given angle of incidence, and a different pure colour at every other angle. To this is due the variegated and changing colour of opals and of some crystals like chlorate of potash. Any thin plate like a film of oil or a soap-bubble can give colours, by reflection from its two surfaces, but a series of slightly reflecting layers, regularly arranged, can give a much purer and more beautiful set of colours. Insects' wings are well known to exhibit this iridescent effect.

The co-operation of small fractions of waves reflected from a regular series accounts for many important phenomena. It can be lightly illustrated by the sound or echo from equally spaced railings: the echo of a tap on the pavement can be a sort of whistle. In the case of light this same effect has important consequences. A spectrum can be formed, not only by bending rays of light, but also by reflecting them from a discontinuous reflector like a grating or finely ruled or laminated surfaces; and by using the ultra-fine natural molecular discontinuities in a crystal, it has been possible to form a spectrum even of X-rays. By this means an extraordinary amount has been ascertained about the arrangement of atoms in a crystal, and even about the structure of the atoms themselves. A recent illuminating, though elementary, book by Sir William Bragg entitled, "On the Nature of Things," gives an admirably clear exposition of the results of this refined analytical process.

Optical Phenomena.

Emission and absorption are mainly atomic properties; and an atom is able to absorb much the same radiation as it can emit. The real emitter is now known to be the electric charges of which the atom is composed. Emission takes place whenever the constitution of an atom is shocked: it may be shocked by collision or external impact, or it may experience a sort of internal catastrophe like an earthquake subsidence. Whenever an electron drops nearer the nucleus of an atom, radiation is emitted. When radiation is absorbed, the electrons are jerked back again, or sometimes jerked out

of the atom altogether—a process which is called "ionisation." The ionising power of a beam of light depends on its wave-length: and the shorter the wave the more effective it is in the ionising process. We are beginning to think that photographic effects are accomplished primarily by the ionising power of the radiation: and it may be the ionising power of visible light which excites the retina of the eye.

Before Clerk Maxwell we did not know what light waves consisted of: we now know that every electric oscillation emits some waves, but that to get waves of any power the oscillations must be very rapid. A discharging capacity, such as a leyden-jar, can easily give vibrations at the rate of a million a second, and therefore can emit waves 300 metres long.

All ether waves can be polarized—that is, made to vibrate in a definite fashion. A vertical aerial will generate electrical vibrations in a vertical plane, the magnetic vibrations being at right-angles or horizontal. Such radiation is said to be polarized. If we had a large number of radiators inclined at all angles, the radiation would not be polarized, but would be analogous to common light. By the properties of crystals, by reflection, and by other methods, it is possible to restore regularity to common light; either separating the horizontal and vertical components, and sending them along different paths, or else transmitting one and suppressing the other. The polarization of light can thus be illustrated, not only by Hertz's waves, but quite easily by visible light, and also (though not so easily) by X-rays.

When two sets of similar waves are superposed, the energy is apt to be distributed in a regular pattern, showing places of extra density and of diminished or zero intensity. These patterns are spoken of as "interference bands" or "interference effects." There is no destruction of energy, but only a redistribution; so that a receiving screen is bright and dark alternately, the bright places being extra bright to compensate for the darkness. A similar phenomenon in sound is known as "beats."

When light waves curl round an obstacle, or penetrate the meshes of a canvas or grid, somewhat similar effects are produced, which are said to be due to diffraction. For these effects to be well marked, the obstacles have to be comparable to the wave-length in size. If the obstacles are big they only cast shadows; but if the obstacle has a sharp clear edge, like a knife-blade, and if the source of light is a point or thin wire, and not a luminous surface, the shadow will be fringed

with light and dark bands, differing in breadth according to the size of the obstacle compared with the wave-length, and therefore showing colours when white light is employed. A series of narrow obstacles like a wire grating can cast an extraordinarily variegated and rather beautifully patterned shadow, exhibiting the effects of diffraction in a marked way. Some natural objects which are ribbed in a regular manner, like some shells, can imitate the effect of gratings: and the familiar colours of these objects are due to diffraction, or the curling of waves round small or narrow obstacles which either obstruct or reflect them.

Thus the phenomena familiar in optics are :—

(1) *Reflection*, as when waves rebound from an opaque object.

(2) *Refraction*, as when they encounter a partially transparent obstacle and have their direction of advance changed. *Dispersion* or spectrum analysis follows, since the different waves are bent differently. The whole theory of optical instruments, such as telescopes and microscopes and cameras, fall under these two heads.

(3) *Diffraction* occurs when the waves encounter a sharp edge or a regular series of obstacles, and curl round them.

(4) *Polarization* is the term applied when the vibrations are regularised, so that the oscillations occur either in straight lines or circles or ellipses, and continue the same without irregularity.

(5) *Absorption* is experienced when wave energy is quenched and converted into the agitated molecular motion we call heat.

(6) *Ionisation* is a remarkable phenomenon observed when the waves partially discompose or interfere with the structure of an atom, a subject which is also known as photo-electricity.

(7) *Interference*, or conflict of waves, occurs when a beam of light is separated into two parts, and reunited: or when radiation travels by two different paths to the same spot, the paths being of unequal length. Interference of waves that have travelled by different paths is considered by some wireless operators to be responsible for the curious effect they stigmatise as "fading."

All these properties can be illustrated by waves of every length, though very different kinds of apparatus have to be employed; just as in engineering, different apparatus has to be used for dealing with, say, grains of wheat or shot on one hand, and girders, bridges, and mountain masses on the other.

Reflection, Refraction, etc., applied to Radiation Generally.

Radio-active substances not only emit waves but also particles — electrified particles. Such particles are also emitted from an electrified negative surface in a vacuum, when they are called "cathode rays," also from some illuminated surfaces, when they are called "photo-electricity," and from heated bodies, when they are called "thermionic emission." A continuous supply of electrons can be obtained by keeping a hot wire supplied with negative electricity: these are the electrons made use of in vacuum valves, constituting an extremely sensitive and rectifying relay—"rectifying" because the freed particles inside the bulb only convey negative electricity, not positive; and very perfect as a relay because of the extreme mobility and docility of the highly charged and exceedingly light particles.

About every one of the subjects thus mentioned in this cursory summary, an immense amount might be said. Radiation is a vast subject, covering nearly all the connexion between ether and matter: it is impossible to do justice to it in a general introduction. One can only take a bird's-eye view of the territory, and get people to realise what a wealth of information has been obtained by the explorers who for the last hundred years have examined and erected beautiful structures upon what had previously been an unknown continent.

Why is so much importance attached to radiation? Because it is the best-known and longest-studied link between matter and ether, and involves the only property we are acquainted with that affects the unmodified great mass of ether alone. Electricity and magnetism are associated with the modifications or singularities called electrons: most phenomena are connected still more directly with matter. Radiation, however, though excited by an accelerated electron, is afterwards let loose in the ether of space, and travels as a definite thing at a measurable and constant pace—a pace independent of everything so long as the ether is free, unmodified, and

unloaded by matter. Hence radiation has much to teach us, and we have much to learn concerning its nature.

A strange thing is that radiation is showing signs of becoming atomic or discontinuous. The corpuscular theory of radiation is by no means so dead as we thought it was. Some radiation is certainly corpuscular; and even the ethereal kind shows indications, which may be and probably are misleading, that it is spotty, or locally concentrated into points, as if the wave-front consisted of detached specks or patches, thus suggesting that the ether may be fibrous in structure, and that a wave runs along line of electric force, as the genius of Faraday surmised might be possible. A recent modification of that view is that a wave-front may be accompanied by concentrated vortex rings or other projectiles—somewhat as the spreading-out jet from a fire engine, when used for dispersing a crowd, might be accompanied by solid pellets capable of hurting individuals, instead of only administering a broadcast wetting.

A speckled or discontinuous character for a wave-front must be regarded as highly improbable: the remarkable thing is that any facts should have suggested such an idea. What seems quite certain is that the characteristic or specific radiation appropriate to each kind of atom is always emitted or absorbed in jerks, not continuously—the structure of the atom being such as to forbid its interaction with the ether except as the result, or at least as the accompaniment, of an internal convulsion. A definite experiment has proved that the smooth motion of matter as a whole has no grip on the ether. There are only a certain number of convulsions possible among the electronic constitutents of an atom, and each of them is associated with a certain definite frequency of ether waves, which if of the right kind are then freely either emitted or absorbed.

Apart from sudden jerks or internal convulsions, an atom behaves like a rigid body, and is unable either to impart or receive energy, or to interact with the ether, by mere motion to and fro. This kind of molecular motion constitutes *temperature*, and radiation is only emitted by a hot body when atoms are jostled together—as must occasionally happen even at low temperatures in accordance with the laws of probability. Such indirect or temperature radiation is most perfectly exhibited by assemblages of atoms to which the term "black" can be applied: it contains waves of all lengths, though in very varying proportions, the most prevalent

wave-length depending on the absolute temperature of the body, and the total amount of radiation being proportional to the fourth power of that temperature. By analysing the distribution of energy in a continuous spectrum of this kind the temperature of the source can be inferred; and it is in this way that the temperature of the sun has been ascertained. Its most prevalent wave-length comes in the yellow of the visible spectrum; whereas for bodies at lower or furnace temperatures the maximum is down in the infra-red.

Whatever be the truth in this matter, a discussion on radiation will continue for a long time, and the outcome cannot fail to yield a much closer insight into the connexion between ether and matter—a problem of the highest physical and philosophic interest, which may have consequences of the utmost importance to humanity.

PART III.—GENERATION OF LONG WAVES.

The radiation we have hitherto mainly dealt with has been the radiation spontaneously emitted by atoms of matter; some of it corpuscular, like alpha rays and beta rays, which consist of material particles shot out with great velocity, but most of it consisting of ether waves, likewise emitted spontaneously by atoms when they are jostled or flung against each other or otherwise violently perturbed. None of this radiation can really be produced artificially: it all depends on the properties of the atoms themselves. All we can do is to subject them to such conditions that they can exercise their powers—which for the most part is done by utilising the energy of their molecular or chemical combinations, whereby they are thrown into the random agitation that we call heat or temperature; that is, by making them move vigorously among themselves, so as to bring about the necessary collisions. Even this process, however, fails to excite or increase the corpuscular radiation from radio-active substances. That emerges spontaneously from sufficiently complex atoms at its own time and rate, and seems at present not to be subject to our control; for the process is not hastened by thermal agitation, nor is it slowed down by extreme cold.

The nearest approach to direct and purposeful production of short-wave radiation is achieved by the cathode rays in a vacuum-tube, which can be excited electrically by familiar

means. For when a current is driven through a vacuum-tube from a source at high potential, high-speed electrons are the carriers of the current; and when these are suddenly stopped by an obstacle or target in their path, they generate by their stoppage the high-frequency or short-wave radiation called X-rays.

Some years before X-rays were discovered, however, Hertz found out how to generate long ether waves on somewhat the same plan, by utilising the crowd of electrons which are loose in a metallic conductor. When a current is established in a straight wire of finite length, its loose electrons are set moving, somewhat after the fashion of the cathode rays in a vacuum: and when they reach the ends of the wire they cannot proceed farther, but are reflected, surging back again, what is left of their energy being reflected at the other end of the wire. In so far as they thus oscillate to and fro in the length of the wire, their oscillations generate a wave of length comparable to twice the length of the wire: much as the air in an open organ pipe, surging up and down in the pipe, generates sound waves twice the length of the pipe. But both the organ pipe and the electric wire require maintenance, for the oscillations damp out very rapidly. By giving some capacity to the ends of the wire, by means of terminal knobs or plates, the wave can be lengthened and the succession a little prolonged. By coiling the middle of the wire into a close spiral, the effective inertia of the particles can be increased (like using a heavy pendulum instead of a light one), and therey the oscillations can be a good deal prolonged, so that a single stimulus can generate a train of waves, with a definite frequency or tune.

A similar arrangement at a distant station immersed in the stream of waves (which as they spread out in all directions must sooner or later reach it) can be set oscillating by them in the same way and with the same frequency; thus constituting a tuned receiver, in which the electrons are made to surge by the impact or influence or inductive effect of the waves. The experiment of the tuned or synchronised leyden-jars, each with a carefully closed circuit (first described in *Nature* for February 20, 1890), lies at the basis of all tuned wireless, and is the foundation of the wave-meters used in connexion with it. In this arrangement one of the jars responds by overflow or side-spark to the synchronous oscillations of the other, or indeed to waves from a distant station if they are exactly of the right frequency.

It has long been known that one conductor could inductively affect another when they were fairly near each other, an oscillating current artificially produced in one setting up a secondary or induced current in the other: but until the time of Hertz it was not known that actual waves would break off from an oscillating current at a certain distance and travel out independently into space with the speed of light. Even though, in accordance with the theory of Clerk Maxwell, some such effect was anticipated by FitzGerald and others, it was not known that these waves could be detected by a similar conductor—detected even when it was at a considerable distance from the source. Hertz found that the excited or responsive surgings were strong enough to produce little sparks or scintillæ, and these little sparks constituted his detector. Soon afterwards the coherer was applied instead of the small spark gap, thereby giving a much more sensitive means of detection; and FitzGerald began to find that a coherer acted to some extent as a rectifier or valve, transmitting oscillations of one sign more easily than the other, so that a sensitive galvanometer could be used even without a battery. But very soon it was found that crystals achieved this rectification much better than metals; and presently Fleming found that the electrons in a vacuum could achieve the purpose still better than a crystal, or at any rate with clearer knowledge of what was happening. Thus the vacuum valve began, was converted into a magnifier by Lee de Forest, and modern wireless telephony became possible.

The electrical oscillations themselves, being of the order of a million a second, are far too rapid for any instrument to detect. But when they are rectified, so that only the positives or only the negatives are transmitted, a group of high-frequency waves becomes a single stimulus: and an ordered succession of such groups may follow each other at intervals corresponding to a hundred or a thousand rectified groups a second, thus bringing them easily within the range of sound, and enabling a telephone and a human ear to respond.

Analogies between Long- and Short-Wave Phenomena.

All this may be considered now well known; but, inasmuch as it has all happened within the lifetime of most of us, a short summary like the above is not inappropriate. For our present purpose the interest of these long-wave phenomena, which can be produced and detected under complete control,

lies in the information they give and the analogies they show about the other older, more intangible and obscure, processes which are responsible for the generation and detection of the short ether waves that we call light, or radiant heat, or ultra-violet, or X-rays. A single Hertz radiator, or wireless aerial, vibrates at a given frequency and emits waves of one wave-length—one tone or one colour, as it were. But a sending station could be imagined in which were a large number of differently attuned aerials, from which there would emerge radiation not with a single wave-length, like a definite colour, but more like a multiplicity or mixture of colours analogous to white light. Different receiving stations might be also imagined, scattered about in different places, each one of which would respond only to a definite frequency of vibration: one to long waves, another to short waves, with others of intermediate character. Each of these stations would thus take up or absorb some of the energy appropriate to its particular frequency or wave-length: we should have what is called "selective absorption." If there were a group or interposed screen consisting of a large number of such stations attuned to the same wave-length, that particular portion of energy would be removed from any train of waves which passed the screen of receivers, so that the waves would go on without that particular wave-length,—a process which is analogous to the production of colour by selective absorption. White light going through a certain kind of glass might leave behind it, absorbed in the glass, the waves corresponding to green and blue, so that what was transmitted was only the red; the effect on a receiving eye would then be a red sensation, and the glass would be called red glass.

A whole set of phenomena of this kind are, and long have been, familiar in optics. A source of coloured light emits only one or a few wave-lengths; and those same wave-lengths it is able to absorb, for they correspond to the frequency to which its atoms happen to be attuned. The processes of selective radiation and absorption in optics are quite analogous to the employment of a number of different signalling stations, each with its own wave-length, and to a still larger number of receiving stations, each of which can be attuned to one or other of the wave-lengths. In optics we have to choose the selectors by employing the appropriate chemical substance. We know that certain dyes will absorb some colours and transmit or reflect others: we know the properties of certain

pigments, vermilion, gamboge, indigo, and the rest: and when we want to deal with the waves which excite a certain colour sensation, we use the appropriate pigment. We have no other means of control; we must depend on the properties of the specific atoms or molecules to give the desired result.

When we work with long waves on the large scale, the whole process is better understood and more within our control. We can adapt a receiving station to respond to any of the others by merely turning a handle—that is, by altering the electric capacity of the receiver, or altering its magnetic inertia or inductance—that is, by changing either its electric or its magnetic property,—or both. Thus we can detect waves over a considerable range, picking out the station we want to hear: just as a painter picks out a pigment and puts it in a certain place where he wants you to see it. The different pigments in a picture are like different receiving stations, each attuned to its own wave-length; and the white light which illuminates the picture comes from a source emitting all those wave-lengths and many others. One *might* illuminate the picture by a single wave-length only—say, by red light. Then the red pigments in the picture would all respond, while the others would remain dark. If the incident light is now changed to, say, green, another set of pigments—that is, another set of signalling stations—would respond; and the red ones would remain dark and ineffective.

Long-wave stations, like the Eiffel Tower or Chelmsford, might be said to be far down in the infra-red. The visible portion of the spectrum of wireless stations may be said to lie in the range permitted for broadcasting purposes. The whole "octave" corresponding to a visible spectrum is by no means yet consumed; or rather the red end of it is used up by the Navy and other official stations. Broadcasting is at present confined between the limits of wave-length from 500 to 300 metres, which corresponds in a spectrum to a range from orange to blue. The civil list of broadcasting stations begins in the yellow with Aberdeen 495, continues through Swansea 485, Birmingham 475, Belfast 435, Glasgow 420, etc., etc., and finishes in the blue with Stoke 306, and Sheffield 301. London, 2 LO, comes in the green, with the wave-length 365. Some amateurs are beginning to get good and distant results by exploitation of the short waves analogous to ultra-violet—200 or even 50 metres. The analogous wave-lengths in actual light are also usually expressed in metres, but in metres divided by 10^{10}—which

are technically known as Angström units of length, and are comparable in size to the diameter of atoms. The wave-length of yellow light is about 5,800 of such units.

That must suffice to show how closely the analogy can be worked between the apparently quite different phenomena of long-wave and short-wave radiation; they both consist of waves in the ether obeying the same laws, travelling at the same rate, and causing appropriately attuned mechanism to respond. In the eye we have such a mechanism concealed in the retina, on a minute scale; and we have reason to say that the normal eye has three kinds of receiving instruments or particles, one responding to a certain shade of red, another to a certain shade of green, and another to a kind of violet. Those three constitute our primary colour sensations, and of them in different proportions all our sense of colour is derived.

The receiving stations in the retina are almost certainly atomic, different atoms responding to the different waves. How, when they respond, they manage to stimulate the nerves—that is to say, what is the nature of the apparatus which converts the energy of ether waves into the energy of a nerve stimulus—is not yet fully known. We know how it is done on the large scale: we use rectifying valves or crystals and a telephone, and thereby convert the ether vibrations into sound vibrations suitable for stimulating the human ear. Somehow, on a minute and very perfect scale, something corresponding to this is automatically done in the eye. It is suspected that it must be done photo-electrically, for it is known that certain atoms respond to radiation of a given wave-length by ejecting an electron, and ejecting it with such energy that it may well be conceived of as exciting a nerve.

Whether this is the explanation of vision or not, it must be manifest that the intelligent production and detection of long-wave radiation, by apparatus humanly constructed and understood, is likely to throw a flood of light on the other processes which men and animals have always made use of without in the least understanding what is happening. The physiological instruments are extraordinarily efficient, with many more complicated peculiarities than our crude physical instruments possess, and yet they act in complete obedience to the laws of physics and chemistry. The physiological mechanism makes full use of these laws, even the most recently discovered and most intricate of them, but in many ways its

behaviour supplements and transcends all known laws under the mysterious influence of life.

It is indeed by life that all our instruments are constructed —those in the laboratory as well as those in the organism; and the construction of laboratory instruments involves not only life but intelligence; they are consciously adapted to their purpose. The instruments in the organism are quite unconsciously constructed by the organism, in ways we have scarcely begun to understand: but whether design and consciousness of some higher kind are involved in those too (perhaps in some indirect and prearranged manner) is a matter on which everyone is not agreed, and on which our views may become clearer and more certain as time goes on and knowledge increases. To some minds the analogy will seem helpful and stimulating: to others it may seem mistaken and misleading.

The Royal Society is concerned with the advancement of Natural Knowledge. All knowledge is natural in the long run: but all knowledge is very far from being attained. In order to progress we must limit ourselves—or those who pursue natural knowledge feel that they must limit themselves—to that which we at present know or can soon hope to know; realising, however, that there is still an infinity which we do not know, and showing wisdom in not denying that which at present lies outside our intellectual ken. For that region lies open to faith and to the higher imagination possessed by poets and seers, who exercise a faculty which, though it goes beyond the intellect, is still truly among the functions and privileges of man.

THE ELECTRON.

By Sir J. J. Thomson, O.M., F.R.S.

Electrons are particles of exceedingly small mass carrying a charge of negative electricity; there is only one kind of electron, for all electrons have the same mass and carry the same electric charge. Until the discovery in 1897 of the electron, the smallest mass known to science was that of an atom of the lightest element, hydrogen, but the mass of this atom is 1,800 times greater than that of an electron. The mass of an electron is by far the smallest of all known masses. The electrons are the bricks which build up the atom; an atom of hydrogen contains one electron, an atom of oxygen eight, one of lead about one hundred, and so on. Differences in the number and arrangements of the electrons in the atom are supposed to account for the difference in the properties of the atoms of the different chemical elements.

Although the electron is by far the commonest and most widely distributed thing known, it was not discovered until 1897, and then in what may be called a highly specialised region. It had been shown by Plücker in 1859 that when an electric current passes through a gas at a low pressure, the glass tube in which the gas is contained phosphoresces in the neighbourhood of the cathode. The phosphorescence is due to something travelling in straight lines from the cathode, for if an obstacle such as a piece of glass rod is placed between the cathode and the walls of the tube, a shadow of the obstacle is thrown on the wall. The nature of the "cathode rays," as the agents which produce this phosphorescence are called, was the subject of a long controversy. One view was that they arose from waves in the ether, another that they were due to negatively electrified particles. In support of the latter view were the facts that negative electricity travelled along the direction of the rays, and that the rays were deflected by a magnet; but against the view was the fact that the rays could pass through thin sheets of metal, such as gold foil. If these rays are electrified bodies, it is possible by certain methods to determine their mass,

velocity and electric charge, and when this was done it was found that the carriers were not atoms or molecules, but something almost infinitesimal in comparison.

The mass and velocity of the electron were determined by measuring the deflexions they experienced when acted on by electric and magnetic forces. Suppose the electron started off horizontally in a discharge tube. It it were not acted on by any forces it would strike the glass wall of the tube at a point opposite its starting point, and the place of impact would be marked by a patch of phosphorescence. If, however, it is acted on by a constant electric force X, acting vertically downwards, the electron would have a downward acceleration Xe/m (if e is its electric charge and m its mass), and would fall just as a rifle bullet shot off horizontally would fall under gravity. The vertical fall of the bullet is $g \cdot l^2/2v^2$, where l is the horizontal distance passed over, v the velocity of projection, and g is the acceleration due to gravity. Putting Xe/m, the acceleration of the electron, instead of g, we see that the distance fallen through by the electron will be $X(e/m)l^2/2v^2$. Hence the electron acted on by the electric force will hit the glass at a point which is this distance below its original destination. If h is the deflexion

$$h = \frac{X}{2}\left(\frac{e}{mv^2}\right) l^2 ;$$

we can measure h, X, and l, and hence from this equation we can get e/mv^2.

If instead of acting on the electron by an electric force we act on it by a magnetic one, at right angles to the direction of motion, the force on the electron due to the magnet is Hev, where H is the strength of the magnetic field ; hence the acceleration is Hev/m, and is at right angles to the path of the particle and in the direction of the magnetic force. Now suppose we let both the electric and magnetic forces act simultaneously, and let one act upwards and the other downwards. We can adjust the two forces until the accelerations due to them just balance, and the electron will then move as if neither electric nor magnetic force acted on it, and the phosphorescence will occur on the tube at the same point as that affected by the electron before either electric or magnetic force was introduced. For the accelerations to be equal

$$\frac{Xe}{m} = \frac{Hev}{m} \text{ or } v = X/H.$$

We can measure both X and H, and thus determine v. We have previously determined e/mv^2, so that when we know v we can find e/m. This was found to be equal to $1 \cdot 8 \times 10^7$.

Now if E is the charge of electricity carried by the hydrogen atom in the electrolysis of solutions, and M the mass of that atom, E/M can be determined by measuring the quantity of hydrogen liberated when a known quantity of electricity passes through an

aqueous solution. This was done long ago, and the result was that $E/M = 10^4$. Special investigations have shown that e, the charge on the electron, is equal to E, the charge on the hydrogen ion; hence since $e = E$ and $e/m = 1 \cdot 8 \times 10^7$, while $E/M = 10^4$, $m = M/1,800$, or the mass of an electron is only $1/1,800$ of that of an atom of hydrogen.

Experiments were made on cathode rays produced with electrodes made of various metals and with different gases in the tube, but the mass of the electron and the charge of electricity it carried were found to be the same whatever might be the nature of the metal or the gas. The velocity of the rays, which was always very high—many thousand miles per second—varied with the potential difference between the electrodes. This high velocity makes the energy of an electron, in spite of its small mass, enormously greater than the energy of the ordinary molecules of a gas. Thus a comparatively slow electron moving with a speed of 30,000 miles per second has 250,000 times the average energy of a molecule of a gas at ordinary temperatures. It is this comparatively enormous energy which makes the detection and study of electrons easier than that of ordinary molecules.

When once electrons had been detected they were found to be very widely distributed. Thus it was found that they were given off by hot wires, and the hot-wire valves now so largely used in wireless telegraphy and for many other purposes work entirely by electrons; electrons are also given off by bodies when struck by ultra-violet light or by Röntgen rays. Radio-active bodies give off very high-speed electrons moving very nearly as fast as light. But whatever may be the means used to liberate them, or the source from which they come, the electrons themselves are always found to be the same.

X-RAYS AND CRYSTAL STRUCTURE.

By Sir William Bragg, K.B.E., F.R.S.

Diffraction of X-rays.

There is a strong analogy between the use of X-rays in the investigation of crystal structure and the employment of light in conjunction with a diffraction grating. There is, however, a very great difference in scale, for the X-ray waves are ten thousand times shorter than those of light. The ordinary diffraction grating consists of a sheet of metal or glass on which parallel lines are ruled, say, 20,000 to the inch. When a ray of homogeneous light is directed upon such a grating, diffracted pencils of light leave the grating in various directions according to well-known rules. That which is least diffracted we call the effect of the first order, and the others are of the second order, the third order and so on. The angles which these diffracted pencils make with the original rays are determined by two factors—namely, the wave-length of the light and the spacing of the lines on the grating, and it is possible, given a wave-length, to find the spacing by measuring the "angle of diffraction." Such a measurement is very exact.

There is another well-known grating effect which is sometimes made use of. The relative intensities of the different orders, but not their angles of diffraction, depend upon the dimensions and form of the groove which the ruling diamond makes on the plate. Sometimes one spectrum is intensified by some particular characteristic in the forms of the grooves. It might be possible to work back from observations of the relative intensities to a determination of the shape of the groove.

When we turn to X-rays, we find the analogue of the light waves in the waves of the X-rays and the analogue of the grating in the ordered arrangement of the crystal. If X-rays are allowed to fall upon a crystal, diffracted pencils may be emitted, and the angle which the diffracted pencil makes with the original ray depends upon the wave-length of the X-rays and the spacings of the crystal.

So far the diffraction of X-rays resembles the diffraction of light by a grating. There is, however, an additional effect in that the direction of the original rays has to be related to the lie of the crystal planes in different ways before any diffraction takes place at all. In the actual experiment the crystal is rotated about some important axis until the diffracted pencil of rays flashes out and the angle of diffraction is then observed just as in the case of light.

The Units in the Structure of Crystals.

The chemical molecule consists of a certain number of atoms arranged in an ordered way. When the molecules are built into a crystal they tend to an arrangement which has a higher symmetry than the molecule itself possesses. We may say that Nature puts together two, three, four or even more molecules in such a way as to make for higher symmetry. In this way she makes a unit of pattern.

The units of pattern are distributed on the lines and planes of a lattice, each unit having exactly the same form, composition and outlook as every other unit; the whole structure of the crystal is an orderly arrangement of these units. They may be considered to lie on various planes or sheets within the crystal just as the rows of trees in an orchard may be considered to lie in various rows, and each sheet corresponds to a line in the light-grating. The X-rays give the distance between sheet and sheet. They may do this for sheets drawn in various ways, and hence it is possible to determine the arrangement of the units in the crystal—that is to say, the form and dimensions of the "cell" occupied by one unit. This measurement corresponds to the determination of the spacing between two lines in the diffraction grating.

A further step which the X-rays can take is the determination of the relative intensities of the various orders of the diffracted rays. This information leads, if it can be interpreted, to a knowledge of the mutual arrangement of the molecules in the crystal. The operation which is always carried out in the case of X-rays, so far as present experience will allow, is analogous to a determination of the form of the grooves of the diffraction grating by measuring the relative intensities of the various orders of diffracted light. Two stages may be distinguished in this process. One of them comparatively easy; the other of difficulty, and sometimes of very great difficulty.

The outer form of a crystal depends upon the internal arrangement of the atoms and molecules, and the group employed by Nature is in general the chemical molecule. It is possible to distinguish thirty-two different classes, each characterised by its own special form. Mathematical crystallography has carried the possibilities of classification further than the outward form can reveal. Taking any group of atoms, it has been shown that in

each class having its special external characteristics there are several ways of arranging the groups so as to give the same outward appearance. These different methods of arrangement are nearly always distinguishable from one another by their action on the X-rays. There are in all 230 of them. An early result of the X-ray analysis is, therefore, the determination of the special arrangement of the molecules within the crystal.

The next stage, the more difficult one, is a determination of the full linear and angular relations between the position of the molecules and the atoms within the molecules. The aids to this determination are relative measurements of intensities of diffraction as revealed by X-rays, to which must be added all that may be known of the chemical, physical and mechanical characteristics of the atoms and the molecules. In some simple cases the analysis may be said to be already complete, but in the hundreds of thousands of known crystals there is, of course, an immense field still to be covered. Models can be constructed, based on the results already obtained, which illustrate the structure of many crystalline substances.

Interpretation of Crystal Structure.

It will now be convenient to refer to some of the principles of structure which X-ray analysis has already revealed. It is clear that such principles are worthy of careful investigation, for they may throw light on chemical and physical actions and also help in further determinations of crystal structure. There is in the first place a broad division into different methods of combination between the atoms. Three types can be recognised. The first of these is illustrated by such crystal structures as rock-salt, fluorspar, calcite and so forth. The structure depends mainly upon a group formed in obedience to laws of electrostatic action. If, for example, we take the case of rock-salt, the chlorine atom has taken away from the sodium atom one electron which it has incorporated into its own structure. According to the modern views of atomic constitution the chlorine atom, which has seven electrons in its outermost electron shell, is eager to complete the shell—completion implying the presence of eight electrons in that shell. Neon, which has eight, already seems to show by its unwillingness to enter into chemical combination—in other words, by its unwillingness to give, take or share electrons—that there is something which makes the eight a satisfactory and complete number. Sodium has the completed outer shell of eight and one which is the beginning of a new shell external to the old. It appears to have a poor hold on this odd electron, so that chlorine easily removes it. In consequence the chlorine becomes a negatively charged body, and the sodium a positively charged body.

Each positive surrounds itself with as many negatives as possible, and each negative with as many positives as possible. The cubic structure of rock-salt is obtained in this way, each atom having six neighbours of opposite sign. In fluorspar, where the calcium atom has been robbed of its two extra electrons by two fluorine atoms, each of which takes one, Nature has found a structure in which the positively charged calcium is surrounded by eight negative fluorines, and the fluorines by four calciums. In Iceland spar the same principle governs the structure. Each calcium atom is surrounded by six CO_3 groups, and each CO_3 group by six calciums. The structure is not, however, so regular as in rock-salt because the CO_3 group is not spherical in form and characteristics. There is a large class of crystals built on the same plan.

There is a certain indefiniteness about the molecule because a positive can be associated with any one of the six negative neighbours which it possesses. It is notable that, in the calcite, the CO_3 group must have such a degree of symmetry as is represented by the properties of an equilateral triangle. If it is turned round 120° in its own plane, it has the same appearance as before. This implies that the three oxygen atoms are all alike in their relations to one another, and to the other atoms of the crystal. However the crystal may come to pieces under chemical action, a compound of calcium atoms and CO_3 groups is not a mixture of CO_2 and CaO. It is supposed that the carbon atom is stripped of all the four electrons which it normally possesses in its outer shell, while the calcium atom loses the two electrons which it has outside its completed shell. Each of the oxygen atoms takes two of the six electrons thus set free. Consequently each carbon atom has a quadruple positive charge, each oxygen a double negative charge, and the calcium a double positive charge.

A second method of combination is to be found in the diamond. The carbon atoms, of which alone it consists, are so arranged that each carbon has four neighbours arranged about it in tetrahedral fashion. Each shares two electrons with each of its neighbours, and in this way covers itself with the desired shell of eight electrons. It appears that the sharing produces a very strong bonding; the diamond is the hardest of known substances.

In graphite there are sheets of atoms tied tightly to one another by the sharing bonds of the diamond, but these sheets are separated from one another by a considerable interval. In this way may be explained the slipperiness of graphite and its usefulness as a lubricant, because in the first place the layers slip on one another easily, the bonds that tie them together being weak, and, in the second place, the atoms in each layer hold tightly together. There are indications that these tight bonds are much less affected by temperature than bonds of a looser type. For example, the co-efficient of expansion with heat of the diamond is far less than

the average expansion of graphite, but the expansion of graphite takes place almost entirely through increased separation of the layers.

Organic Crystals.

There is yet a third method of combination, in general much weaker than the other two. When molecules, as in organic crystals, are built together into a structure, the forces that bind together molecule and molecule may be comparatively weak. The separate molecules are not positive or negative to each other, nor do they share electrons, but no doubt there are stray fields, perhaps electric, perhaps magnetic, at different points on their surfaces which cause the molecules to be joined on to one another like the girders of an iron bridge. The crystal structure is very empty; it is like lace-work in space. We get the first hint of this likeness in the diamond, where the empty spaces are big enough to accommodate as many more carbon atoms as a diamond already contains. The root principle seems to be that the carbon atom, when sharing electrons, gathers round it four neighbours more or less at the corners of a tetrahedron. If these points of attachment are spaced, so to speak, over the surface of the carbon atom, it is easy to understand how it comes about that these open structures can be formed.

In the diamond crystal the structure shows two types of arrangement which form the basis of two of the great groups of organic substances. There is in the first place the hexagonal ring, which appears to be capable of separate existence in unchanged form and dimension, and when fringed with various atoms or radicles, to form the innumerable members of the aromatic series. The double and treble rings are found in naphthalene and anthracene respectively, and the structure of these crystals, as revealed by X-rays, shows that the ring is the same in all respects as in the diamond.

There is also to be found in the diamond an arrangement of long chains, which may have any length, of carbon atoms. These chains, when fringed along their length by hydrogen atoms and finished off at each end with various groups of atoms, such as the methyl group (CH_3), the carboxyl group ($COOH$), the hydroxyl group (OH), and so on, form the well-known chain compounds of organic chemistry. Measurements of the lengths of these chains have recently been made very exactly by the X-ray methods in a number of cases, and it appears that the arrangement is, as the models show, just the same as is found in the diamond. The essential feature is that any two carbon atoms are joined on to a third at points on the surface of the latter, which are, at least, close to tetrahedral points.

Structure of Metals.

The application of the X-rays to the crystal analysis of metals has shown very remarkable results, which will probably receive great extension in the future. Many of the metals aluminium, silver, copper and gold, for example– are of a structure which implies the simplest form of close packing of spherical atoms. These plates are those in which the packing is most dense. A mass of crystals is stronger than a single crystal because the planes of weakness lie in all directions. An admixture of a certain number of foreign atoms causes a distortion of the structure, which diminishes the possibility of slip, and thus the hardening effect of an alloy is explained.

In the case of steel it seems likely that the carbon atoms do not replace iron atoms, as, for example, tin atoms replace those of copper in the formation of bronze; they appear to fit into the interstices of the structure. The structural nature of the various crystals which form in alloys, as, for example, cementite in steel and intermetallic compounds in other alloys, have also been the subject of investigation.

Among the many other developments to which X-ray analysis is leading, one more may be mentioned, It now seems possible from a knowledge of the structure of the atoms which compose the crystal, to calculate the effects upon electro-magnetic waves, such as those of light, on their way through it. A beginning in this respect has been made with the measurements of the refraction indices of calcite and aragonite.

ELECTRICITY AND MATTER.*

By Sir Ernest Rutherford, O.M., F.R.S.

The Electron.

The discovery by Sir J. J. Thomson in 1897 of the individual existence of the negative electron of small mass, and the proof that it was a component of all the atoms of matter, was an event of extraordinary significance to science, not only for the light which it threw on the nature of electricity, but also for the promise it gave of methods of direct attack on the problem of the structure of the atom. This discovery of the electron, coupled with the recognition of the atomic nature of electricity, has created a veritable revolution in our ideas of atoms.

It was soon recognised that the negative electron of small mass was an actual disembodied atom of electricity, and that its apparent mass was electrical in origin. Sir J. J. Thomson had shown so early as 1881 that a charged body in motion behaved as if it had an additional electric mass due to its motion. The moving charge generates a magnetic field in the space surrounding it, resulting in an increase of energy of the moving system which is equivalent to the effect produced by an increase of the mass of the body.

Since there must always be electric mass associated with the movement of electric charges, it is natural to suppose that the mass of the electron is entirely electrical in origin, and no advantage is gained by supposing that any other type of mass exists. If the atom is a purely electrical structure, the mass of the atom itself must be due to the resultant of the electric masses of the charged particles which make up its structure. As only a small fraction of the mass of an atom can be ascribed to the negative electrons contained in it, the main part is due to the positively charged units of its structure.

---

* Abstracted from the Kelvin Lecture delivered before the Institution of Electrical Engineers on May 18, 1922.

THE PROTON.

One of the main difficulties in our attack on the question of atomic constitution has lain in the uncertainty of the nature of positive electricity. The evidence as a whole supports the idea that the nucleus of the hydrogen atom, *i.e.*, a positively charged atom of hydrogen, is the positive electron. No evidence has been obtained of the existence of a positively charged unit of mass less than that of the hydrogen nucleus, either in vacuum tubes or in the transformation of the radio-active atoms, where the processes occurring are very fundamental in character.

It might *a priori* have been anticipated that the positive electron should be the counterpart of the negative electron and have the same small mass. There is, however, not the slightest evidence of the existence of such a counterpart. On the views outlined, the positive and negative electrons both consist of the fundamental unit of charge, but the mass of the positive is about 1,800 times that of the negative. This difference in the mass of the two electrons seems a fundamental fact of Nature, and, indeed, is essential for the existence of atoms as we know them. The unsymmetrical distribution of positive and negative electricity that is characteristic of all atoms is a consequence of this wide difference in the mass of the ultimate electrons which compose their structure. No explanation can be offered at the moment why such a difference should exist between positive and negative electricity.

Since it may be argued that a positive unit of electricity associated with a much smaller mass than the hydrogen nucleus may yet be discovered, it may be desirable not to prejudge the question by calling the hydrogen nucleus the positive electron. For this reason, and also for brevity, it has been proposed that the name "proton" should be given to the unit of positive electricity associated in the free state with a mass about that of the hydrogen nucleus. In the following, the term "electron" will be applied only to the well-known negative unit of electricity of very small mass.

On the classical electrical theory, the mass of the electron can be accounted for by supposing that the negative electricity is distributed on a spherical surface of radius about 1×10^{-13} cm. This is merely an estimate, but probably gives the right order of magnitude of the dimensions.

The greater mass of the proton is to be explained by supposing that the distribution of electricity is much more concentrated for the proton than for the electron. Supposing the shape spherical, the radius of the proton should be only 1/1800 of that of the electron. If this be so, the proton has the smallest dimensions of any particle known to us. It is admittedly very difficult to give any convincing proof in support of this contention, but at the same time there is no evidence against it.

STRUCTURE OF THE ATOM.

Progress during the last twenty years of our ideas on the structure of atoms has depended mainly on a clearer understanding of the relative part played by positive and negative electricity in atomic structure. It is now generally accepted that the atom is an electrical system and that the atoms of all the elements have a similar type of structure.

The nuclear theory of atomic constitution has been found to be of extraordinary value in offering an explanation of the fundamental facts that have come to light, and is now generally employed in all detailed theories of atomic constitution. At the centre of each atom is a massive positively charged nucleus of dimensions minute compared with the diameter of the atom. This nucleus is surrounded by a distribution of negative electrons which extend to a distance, and occupy rather than fill a region of diameter about 2×10^{-8} cm. Apart from the mass of the atom, which resides mainly in the nucleus, the number and distribution of the outer electrons, on which the ordinary physical and chemical properties of the atom depend, are controlled by the magnitude of the nuclear charge. The position and motions of the external electrons are only slightly affected by the mass of the nucleus.

According to this view of the atom, the problem of its constitution naturally falls into two parts—first, the distribution and mode of motion of the outer electrons, and secondly, the structure of the nucleus and the magnitude of the resultant positive charge carried by it. In a neutral atom the number of external electrons is obviously equal in number to the units of positive (resultant) charge on the nucleus.

The general conception of the nuclear atom arose from the need of explanation of the very large deflexions experienced by swift particles thrown off by radio-active substances, known as α- and β- particles, in passing through the atoms of matter. A study of the number of α- particles scattered through different angles showed that there must be a very intense electric field within the atom, and gave us a method of estimating the magnitude of the charge on the nucleus. Similarly, the scattering of X-rays by the outer electrons provided us with an estimate of the number of these electrons in the atom, and the two methods gave concordant values. The next great advance we owe to the experiments of Moseley on the X-ray spectra of the elements. He showed that his experiments received a simple explanation if the nuclear charge varied by one unit in passing from one atom to the next. In addition, it was deduced that the actual magnitude of the nuclear charge of an atom in fundamental units is equal to the atomic or ordinal number when the elements are arranged in order of increasing atomic weight. On this view, the nuclear charge of hydrogen is 1, of helium 2, lithium 3, and so on up to the heaviest

element uranium, of charge 92. Between these limits, with few exceptions, all nuclear charges are represented by known elements.

This relation, found by Moseley, between the atoms of the elements, is of unexpected simplicity and of extraordinary interest. The properties of an atom are defined by a whole number which varies by unity in passing from one atom to the next. This *atomic number* represents not only the ordinal number of the elements, but also the magnitude of the charge of the nucleus and the number of outer electrons. The atomic weight of an element is not nearly so fundamental a property of the atom as its nuclear charge, for its weight depends upon the inner structure of the nucleus, which may be different for atoms of the same nuclear charge.

THE NUCLEUS OF THE ATOM.

The most definite information we have of the structure of the nucleus of an atom has been obtained from a study of the modes of disintegration of the radio-active atoms. In the great majority of cases the atom breaks up with the expulsion of a single α-particle, which represents the doubly charged nucleus of the helium atom; in other cases a swift β-ray or electron is liberated. There can be no doubt that these particles are liberated from the nuclei of the radio-active atoms. This is clearly shown by the variation of the atomic numbers (the figures enclosed by the circles) of the successive elements in the long series of transformations of uranium and thorium (Fig. 1). The expulsion of an α-particle lowers the

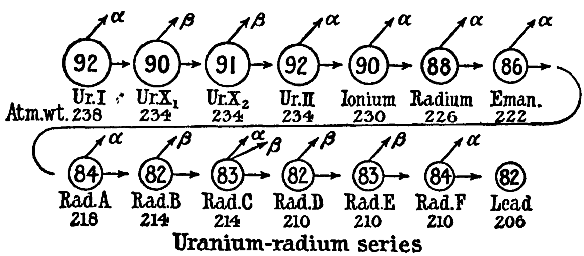

FIG. 1.

nuclear *charge* of the atom by two units and its *mass* by four, while the expulsion of an electron raises its charge by one. On this simple basis we can at once deduce the atomic number and, consequently, the general chemical properties of the long series of radio-active elements. In this way we can understand at once the appearance in the radio-active series of isotopes, *i.e.*, elements of the same nuclear charge but different atomic masses.

The existence of isotopic elements was first brought to light from a study of the radio-active elements. For example, radium-*B*, radium-*D* and the end product, uranium-lead, are isotopes of lead of nuclear charge 82, but of masses 214, 210, and 206 respectively.

As regards ordinary chemical and physical properties, they are indistinguishable from one another, differing only in properties that depend on the nucleus, namely, atomic mass and radio-activity. For example, radium-*B* and radium-*D* both emit β-rays, but with different velocities, while their average life is widely different. Uranium-lead, on the other hand, is non-radio-active. Many similar examples can be taken from the thorium and actinium series of elements. These illustrations show clearly that elements may have almost identical physical and chemical properties, and yet differ markedly in the mass and structure of their nuclei.

From the radio-active evidence, it seems clear that the nuclear structure contains both helium nuclei and electrons. In the uranium-radium series of transformations, eight helium nuclei are emitted and six electrons, and it is natural to suppose that the helium nuclei and electrons that are ejected act as units of the nuclear structure. It is clear from these results that the nuclear charge of an element is the excess of the positive charges in the nucleus over the negative. It is a striking fact that no protons (H nuclei) appear to be emitted in any of the radio-active transformations, but only helium nuclei and electrons.

Some very definite and important information on the structure of nuclei has been obtained by Aston in his experiments to show the existence of isotopes in the ordinary stable elements by the well-known positive-ray method. He found that a number of the elements were simple and contained no isotopes. Examples of such " pure " elements are carbon, nitrogen, oxygen and fluorine. It is significant that the atomic weights of these elements are nearly whole numbers in terms of $O = 16$; on the other hand, elements such as neon, chlorine, krypton, and many others, consisted of mixtures of two or more isotopes of different atomic masses. Aston found that within the limit of error—about 1 in 1,000—the atomic weights of these isotopes were whole numbers on the oxygen scale. This is a very important result, and suggests that the nuclei of elements are built up by the addition of protons, of mass nearly one, in the nuclear combination.

Disintegration of Elements.

There seems to be no doubt that the nucleus of an atom is held together by very powerful forces, and that we can only hope to effect its disintegration by very concentrated sources of energy applied directly to the nucleus. The most concentrated source of energy known to us is the swift α-particle expelled from radium or thorium. It is liberated with a velocity of 10,000 miles per second, and has so much energy that it produces an easily visible flash on striking a zinc sulphide crystal. Its speed is twenty thousand times greater than that of a swift rifle bullet, and, mass for mass, its energy of motion is four hundred million times greater.

A stream of α-particles is therefore made to bombard the atoms of the material under examination. On account of the minuté size of the nucleus, we can expect an α-particle only occasionally to get near enough to the nucleus to effect its disintegration, and this method should be more likely to succeed with a light atom, in which the repulsive force of the nucleus would not be so great as that of a heavy atom with high nuclear charge.

The first observation indicating the disruption of the nitrogen nucleus was made some years ago. When α-particles were passed through oxygen or carbon-dioxide, a few particles of long range were observed. These appeared to be H-nuclei set free from hydrogen in the radio-active source, which, on account of their small mass, would be expected to have a greater range than the α-particles liberating them. When, however, dry air or nitrogen is submitted to such a bombardment, the number of long-range particles is three or four times as numerous, and they have a greater average range. These behaved in all respects as H-nuclei, and it was concluded that they arose from disruption of the nitrogen nuclei.

Using improved apparatus, it was possible to show that similar long-range particles were liberated from boron, fluorine, sodium, aluminium and phosphorus. The range of the particles is in all cases greater than that of the H-particles liberated from free hydrogen atoms under similar conditions. For example, using radium-*C* as a source of X-rays, the range of the H-nuclei is about 28 cm. Under similar conditions, the range of the particles from nitrogen is 40 cm., while the range of particles from aluminium is as much as 90 cm.

It is thus natural to conclude that "protons" have been ejected from the nuclei of certain light elements by the action of the α-particles. It is significant that no protons are liberated from carbon (12) and oxygen (16), the atomic weights of which are given by $4n$, where n is a whole number. Protons are only observed from elements of which the atomic weights are expressed by $4n + a$, where a is 2 or 3.* These results suggest that the elements are, in the main, built up of helium nuclei of mass 4, and protons. The α-particle is unable to liberate a proton from elements like carbon and oxygen, which are built up entirely of helium nuclei as secondary units, probably because the helium nucleus is too stable to be broken up by the swiftest α-particle available. It should be borne in mind, however, that this disintegration phenomenon effected by α-particles is on an exceedingly minute scale. Only two protons are liberated from aluminium for a million α-particles traversing it.

---

* Later experiments have shown that all the elements from boron to potassium are disintegrated by bombardment with α-particles, with the two exceptions of carbon and oxygen.

The Architecture of Atoms.

From the radio-active evidence, we know that the nuclei of heavy atoms are built up, in part at least, of helium nuclei and electrons, while it also seems clear that the proton can be released from the nuclei of certain light atoms. It is, however, very natural to suppose that the helium nucleus which carries two positive charges is a secondary building unit, composed of a close combination of protons and electrons, namely, 4 protons and 2 electrons.

From the point of view of simplicity, such a conception has much in its favour, although it seems at the moment impossible to prove its correctness. If, however, we take this structure of the helium nucleus as a working hypothesis, certain very important consequences follow.

Taking the mass of the oxygen atom as 16 (the standard which is usually adopted in atomic weight determinations), the helium atom has a mass very nearly 4·000, while the hydrogen atom has a mass 1·0077. The mass of the helium atom is thus considerably less than that of four free H-nuclei. Disregarding the small mass of electrons, in the formation of 1 gram of helium from hydrogen there would be a loss of mass of 7·7 milligrams.

It is now generally accepted that if the formation of a complex system is accompanied by the radiation of energy, a reduction of its mass occurs, which can be calculated. In the formation of 1 gram of helium from hydrogen an enormous amount of energy is set free; the energy radiated in forming one single atom of helium is equivalent to the energy carried by three or four swift α-particles from radium. On this view we can at once understand why it should be impossible to break up the helium nucleus by a collision with an α-particle. In fact, the helium atom should be by far the most stable of all the complex atoms.

Most workers on the problem of atomic constitution now take as a working hypothesis that the atoms of matter are purely electrical structures, and that ultimately it is hoped to explain all the properties of atoms as a result of certain combinations of the two fundamental units of positive and negative electricity, the proton and electron. Some of the more successful methods of attack that have been made on this most difficult of problems have been indicated. During recent years unexpectedly rapid advances have been made in our knowledge, but we have only made a beginning in the attack on a very great and intricate problem.

ATOMS AND ISOTOPES.*

By Dr. F. W. Aston, F.R.S.

The Size of Atoms.

That matter is discontinuous and consists of discrete particles is by no means obvious to the senses. The surfaces of clean liquids even under the most powerful microscope appear perfectly smooth, coherent and continuous. The merest trace of a soluble dye will colour millions of times its volume of water. It is not surprising therefore that, in the past, there have arisen schools who believed that matter was quite continuous and infinitely divisible.

The upholders of this view said that if you took a piece of material—lead, for instance—and went on cutting it into smaller and smaller fragments with a sufficiently sharp knife, you could go on indefinitely. The opposing school argued that at some stage in the operations, either the act of section would become impossible or the result would be lead no longer.

The accuracy of modern knowledge is such that we can carry out, indirectly at least, the experiment suggested by the old philosophers right up to the stage when the second school is proved correct, and the ultimate atom of lead is reached. For convenience, we can start with a standard decimetre cube of lead weighing 11·37 kilograms, and the operation of section will consist of three cuts at right angles to each other, dividing the original cube into eight similar bodies, each of half the linear dimensions and one-eighth the weight. Thus the first cube will have 5 cm. sides and weigh 1·42 kilograms, the second will weigh 178 gm., the fourth 2·78 gm., and so on. Diminution in the series is very rapid, and the result of the ninth operation is a quantity of lead just weighable on the ordinary chemical balance. The last operation possible, without breaking up the lead atom, is the

---

*** Abstracted from lectures delivered before the Franklin Institute, Philadelphia, on March 6–10, 1922. Additional data on Isotopes added in 1925.**

twenty-eighth. The twenty-sixth cube contains 64 atoms, the size, distance apart and general arrangement of which can be represented with considerable accuracy, thanks to the exact knowledge derived from research on X-rays and specific heats.

The following table shows at what stages certain analytical methods break down. The great superiority of the microscope is a noteworthy point.

Cube.	Side in cm.	Mass in gm.	Limiting Analytical Method.
9	$0 \cdot 0195$	$8 \cdot 5 \times 10^{-5}$	Ordinary Chemical Balance.
14	$6 \cdot 1 \times 10^{-4}$	$2 \cdot 58 \times 10^{-9}$	Quartz Micro-balance.
15	$3 \cdot 05 \times 10^{-4}$	$3 \cdot 22 \times 10^{-10}$	Spectrum Analysis (Na lines).
18	$3 \cdot 8 \times 10^{-5}$	$6 \cdot 25 \times 10^{-13}$	Ordinary Microscope.
24	$6 \cdot 0 \times 10^{-7}$	$2 \cdot 38 \times 10^{-18}$	Ultra-Microscope.
28	$3 \cdot 7 \times 10^{-8}$	$5 \cdot 15 \times 10^{-22}$	
Atom	$3 \cdot 0 \times 10^{-8}$	$3 \cdot 44 \times 10^{-22}$	Radio-activity.

Just as any vivid notion of the size of the cubes passes out of our power at about the twelfth—the limiting size of a dark object visible to the unaided eye—so when one considers the figures expressing the number of atoms in any ordinary mass of material, the mind is staggered by their immensity. Thus if we slice the original decimetre cube into square plates one atom thick, the area of these plates will total one and one-quarter square miles. If we cut these plates into strings of atoms spaced apart as they are in the solid, these decimetre strings put end-to-end will reach 6·3 million million miles, the distance light will travel in a year, a quarter of the distance to the nearest fixed star. If the atoms are spaced but one millimetre apart, the string will be three and a half million times longer yet, spanning the whole universe.

From the above statements it would, at first sight, appear absurd to hope to obtain effects from single atoms, yet this can now be done in several ways, and indeed it is largely due to the results of such experiments that the figures can be stated with so much confidence. Detection of an individual is only feasible in the case of an atom moving with an enormous velocity, when its energy is quite appreciable, although its mass is so minute. The charged helium atom shot out by radio-active substances in the form of an α-ray possesses so much energy that the splash of light caused by its impact against a fluorescent screen can be visibly detected; the ionisation caused by its passage through a suitable gas can be measured on a sensitive electrometer, and, in the beautiful experiments of Prof. C. T. R. Wilson, its path in air can be both seen and photographed by means of the condensation of water drops upon the atomic wreckage it leaves behind it.

Discovery of Isotopes.

In the first complete Atomic Theory put forward by Dalton in 1803, one of the postulates states that: " Atoms of the same

element are similar to one another and equal in weight." Of course, if we take this as a definition of the word "element" it becomes a truism, but, on the other hand, what Dalton probably meant by an element, and what we understand by the word to-day, is a substance such as hydrogen, oxygen, chlorine, or lead, which has unique chemical properties, and cannot be resolved into more elementary constituents by any known chemical process. For many of the well-known elements Dalton's postulate still appears to be strictly true, but for others, probably the majority, it needs some modification.

The idea that atoms of the same element are all identical in weight could not be challenged by ordinary chemical methods, for the atoms are by definition chemically identical, and numerical ratios were only to be obtained in such methods by the use of quantities of the element containing countless myriads of atoms.

There are two ways by which the identity of the weights of the atoms forming an element can be tested. One is by the direct comparison of the weights of individual atoms: the other is by obtaining samples of the element from different sources or by different processes, samples which, although perfectly pure, do not give the same chemical atomic weight. It was by the second and less direct of these methods that it was first shown that substances could exist which, though chemically identical, had different atomic weights. To these the name "isotopes" was applied by Prof. F. Soddy.

Measurement of Masses of Individual Atoms.

In the absence of the special radio-active evidence which can be used in special cases such as that of lead, the presence of isotopes among the inactive elements can only be detected by the direct measurement of the masses of individual atoms. This can be done by the analysis of positive rays.

The condition for the development of these rays is, briefly, ionisation at low pressure in a strong electric field. Ionisation, which may be due to collisions or radiation, means in its simplest case the detachment of one electron from a neutral atom. The two resulting fragments carry charges of electricity of equal quantity but of opposite sign. The negatively-charged one is the electron, the atomic unit of negative electricity itself, and is the same whatever the atom ionised. It is extremely light, and therefore in the strong electric field rapidly attains a high velocity and becomes a cathode ray. The remaining fragment is clearly dependent on the nature of the atom ionised. It is immensely more massive than the electron, for the mass of the lightest atom, that of hydrogen, is about 1,800 times that of the electron, and so will attain a much lower velocity under the action of the electric field. However, if the field is strong and the pressure so low

that it does not collide with other atoms too frequently, it will ultimately attain a high speed in a direction opposite to that of the detached electron, and become a " positive ray."

Positive rays can be formed from molecules as well as atoms, so any measurement of their mass will give us direct information as to the masses of atoms of elements and molecules of compounds: moreover, this information will refer to the atoms or molecules *individually*, not, as in chemistry, to the mean of an immense aggregate. It is on this account that the accurate analysis of positive rays is of such importance.

In order to investigate and analyse them it is necessary to obtain intense beams of the rays. This can be done in several ways. The one most generally available is by the use of the discharge in gases at low pressure.

The comparatively dimly lit space in a discharge tube between the cathode and the bright " negative glow " is named after its discoverer the " Crookes' dark space." Ionisation is going on at all points throughout the dark space, and it reaches a very high intensity in the negative glow. This ionisation is probably caused for the most part by electrons liberated from the surface of the cathode (cathode rays). These, when they reach a speed sufficient to ionise by collision, liberate more free electrons, which in their turn become ionising agents, so that the intensity of ionisation from this cause will tend to increase as we move away from the cathode. The liberation of the original electrons from the surface of the cathode is generally regarded as due to the impact of the positive ions (positive rays) generated in the negative glow and the dark space. In addition to cathode ray ionisation the positive rays travelling towards the cathode are themselves capable of ionising the gas, and radiation may also play an important part in the same process.

The surface of the cathode will therefore be under a continuous hail of positively charged particles. Their masses may be expected to vary from that of the lightest atom to that of the heaviest molecule capable of existence in the discharge tube, and their energies from an indefinitely small value to a maximum expressed by the product of the charge they carry multiplied by the total potential applied to the electrodes. If the cathode be pierced, the rays pass through the aperture and form a stream, heterogeneous both in mass and velocity, which can be subjected to examination and analysis.

Analysis of Positive Rays.

In Sir J. J. Thomson's " parabola " method of analysis of positive rays, the particles, after reaching the surface of the cathode, enter a long and very fine metal tube. By this means a narrow beam of rays is produced, which is passed through electric and magnetic fields causing deflexions at right angles to each other,

and finally falls upon a screen of fluorescent material or a photographic plate. It can then be shown that if the mass of any particle is m and its charge e, when both fields are on together, the locus of impact of all particles of the same e/m, but varying velocity, will be a parabola. Since e must be the electronic charge, or a simple multiple of it, measurement of the relative positions of the parabolas on the plate enables us to calculate the relative masses of the particles producing them—that is, the masses of the individual atoms. The fact that the streaks were definite, sharp parabolas, and not mere blurs, constituted the first direct proof that atoms of the same element were, even approximately, of equal mass.

Many gases were examined by this method, and some remarkable compounds, such as H_3, discovered by its means. When in 1912 neon was introduced into the discharge tube, it was observed to exhibit an interesting peculiarity. Whereas all elements previously examined gave single, or apparently single, parabolas, that given by neon was definitely double. The brighter curve corresponded roughly to an atomic weight of 20, the fainter companion to one of 22, the atomic weight of neon being 20.20. Sir J. J. Thomson was of the opinion that line 22 could not be attributed to any compound, but that it represented a hitherto unknown elementary constituent of neon. This agreed very well with the idea of isotopes which had just been promulgated, so that it was of great importance to investigate the point as fully as possible.

The first line of attack was an attempt at separation by fractional distillation over charcoal cooled with liquid air, but even after many thousands of operations the result was entirely negative. The second method employed was that of fractional diffusion through pipeclay, which after months of arduous work gave a small, but definite positive indication of separation. A difference of about 0·7 per cent. between the densities of the heaviest and lightest fractions was obtained. It therefore seemed probable that neon was a mixture of isotopes.

The Mass-Spectrograph.

By the time that research on the subject was resumed in 1919, the existence of isotopes among the products of radio-activity had been put beyond all reasonable doubt by the work on the atomic weight of lead. This fact automatically increased both the value of the evidence of the complex nature of neon and the urgency of its definite confirmation. It was realised that separation could only be very partial at the best, and that the most satisfactory proof would be afforded by measurements of atomic weight by the method of positive rays. These would have to be so accurate as to prove beyond dispute that the accepted atomic weight lay between the real atomic weights of the constituents, but corresponded with neither of them.

The parabola method of analysis was not sufficient for this, but the required accuracy was achieved by a new arrangement. The rays, after arriving at the cathode face, are made to pass through two very narrow parallel slits of special construction, and the resulting thin ribbon of rays is spread out into an electric spectrum by means of parallel charged plates. After emerging from the electric field, a group of the rays is selected by means of a diaphragm, and made to pass between the parallel poles of a magnet. By this means the rays are brought to a focus, though spread out spectrum fashion, on a photographic plate.

Thus the instrument is a close analogue of the ordinary spectrograph, and gives a "spectrum" which, however, depends upon mass; it was therefore called a "mass-spectrograph" and the spectrum it produces a "mass-spectrum."

The measurements of mass thus made are not absolute, but relative to lines which correspond to known masses. Such lines due to hydrogen, carbon, oxygen and their compounds are generally present as impurities or purposely added, for pure gases are not suitable for the smooth working of the discharge tube.

It must be remembered that the ratio of mass to charge is the real quantity measured by the position of the lines. Many of the particles are capable of carrying more than one charge. A particle carrying two charges will appear as having half its real mass, one carrying three charges as if its mass was one-third, and so on. Lines due to these are called lines of the second and third order. Lines of high order are particularly valuable in extending the reference scale.

When neon was introduced into the apparatus, four new lines made their appearance at 10, 11, 20 and 22. The first pair are second order lines and are fainter than the other two, and a series of consistent measurements showed that to within about one part in a thousand the atomic weights of the isotopes composing neon are 20 and 22 respectively. Ten per cent. of the latter would bring the mean atomic weight to the accepted value of 20·20, and the relative intensity of the lines agrees well with this proportion. The isotopic constitution of neon seems therefore settled beyond all doubt.

The element chlorine was naturally the next to be analysed, and the explanation of its fractional atomic weight was obvious from the first plate taken. Its mass spectrum is characterised by four strong first order lines at 35, 36, 37, 38, with fainter ones at 39, 40. There is no sign whatever of any line at 35·46. The simplest explanation of the group is to suppose that the lines 35 and 37 are due to the isotopic chlorines and lines 36 and 38 to their corresponding hydrochloric acids. The elementary nature of lines 35 and 37 is also indicated by the second order lines at 17·5, 18·5, and also, when phosgene was used, by the appearance of lines at 63, 65, due to $COCl^{35}$ and $COCl^{37}$.

Later it was found possible to obtain the spectrum of negatively-charged rays. These rays are formed by a normal positively-charged ray picking up two electrons. On the negative spectrum of chlorine only two lines, 35 and 37, can be seen, so that the lines at 36 and 38 cannot be due to isotopes of the element. These results go to show that chlorine is a complex element, and that its principal isotopes are of atomic weight 35 and 37.

The method of positive ray analysis having been applied so successfully to neon and chlorine, other elements were quickly submitted to its searching investigation. About half turned out to be mixtures and some are very complex. Thus krypton has six, tin at least seven, and xenon possibly nine constituents. It was also demonstrated definitely that hydrogen is a simple element and that its chemical atomic weight, 1·0077, is the true weight of its atom (*see* p. 36). Positive rays of the metallic elements cannot, in general, be obtained by the discharge tube method, but require special devices. Thus the isotopic nature of lithium was first demonstrated by the use of anode rays derived from anodes containing salts of that metal, and since then, all the other alkali metals have been successfully analysed.

A powerful and ingenious method of generating positive rays of metallic elements has been used with great success by Dempster at Chicago. He employs the element in the metallic state, and ionises its vapour by means of a subsidiary beam of cathode rays. The ions so produced are allowed to fall through a definite potential, and, being therefore of constant energy, can be analysed by the use of a magnetic field alone. By this arrangement Dempster discovered the three isotopes of magnesium, and has since analysed zinc and calcium.

By a special arrangement called the method of accelerated anode rays, it was found possible in 1923 to extend mass spectrum analysis to a large number of metallic elements, so that more than half the known elements have now been analysed.

A complete list of the isotopes of the non-radio-active elements so far discovered is given in the following table :—

Table of Elements and Isotopes.

Element.	Atomic Number.	Atomic Weight.	Minimum number of Isotopes.	Mass-numbers of Isotopes in Order of Intensity.
H	1	1·008	1	1
He	2	3·99	1	4
Li	3	6·94	2	7, 6
Be	4	9·1	1	9
B	5	10·9	2	11, 10
C	6	12·00	1	12
N	7	14·01	1	14
O	8	16·00	1	16

Table of Elements and Isotopes—continued.

Element.	Atomic Number.	Atomic Weight.	Minimum number of Isotopes.	Mass-numbers of Isotopes in Order of Intensity.
F	9	19·00	1	19
Ne	10	20·20	2	20, 22
Na	11	23·00	1	23
Mg	12	24·32	3	24, 25, 26
Al	13	26·96	1	27
Si	14	28·3	2	28, 29, 30
P	15	31·04	1	31
S	16	32·06	1	32
Cl	17	35·46	2	35, 37
A	18	39·88	2	40, 36
K	19	39·10	2	39, 41
Ca	20	40·07	2	40, 44
Sc	21	45·1	1	45
Ti	22	48·1	1	48
V	23	51·0	1	51
Cr	24	52·0	1	52
Mn	25	54·93	1	55
Fe	26	55·84	2	56, 54
Co	27	58·97	1	59
Ni	28	58·68	2	58, 60
Cu .. .	29	63·57	2	63, 65
Zn	30	65·37	4	64, 66, 68, 70
Ga	31	69·72	2	69, 71
Ge	32	72·5	3	74, 72, 70
As	33	74·96	1	75
Se	34	79·2	6	80, 78, 76, 82, 77, 74
Bi	35	79·92	2	79, 81
Kr	36	82·92	6	84, 86, 82, 83, 80, 78
Rb	37	85·45	2	85, 87
Sr ..	38	87·63	2	88, 86
Y	39	88·9	1	89
Zr	40	(91)	3, (4)	90, 94, 92, (96)
Ag	47	107·88	2	107, 109
Cd	48	112·41	6	114, 112, 110, 113, 111, 116
In	49	114·8	1	115
Sn	50	118·7	7, (8)	120, 118, 116, 124 119, 117, 122, (121)
Sb	51	121·77	2	121, 123
Te	52	127·5	3	128, 130, 126
I	53	126·92	1	127
X	54	130·2	7, (9)	129, 132, 131, 134, 136, 128, 130, (126), (124)
Cs	55	132·81	1	133
Ba	56	137·37	(1)	138
La	57	138·91	1	139
Ce	58	140·25	2	140, 142
Pr	59	140·92	1	141
Nd	60	144·27	3, (4)	142, 144, 146, (145)
Hg	80	200·6	(6)	(197–200), 202, 204,
Bi	83	209·00	1	209

(Numbers in brackets are provisional only.)

SIGNIFICANCE OF THE DISCOVERY OF ISOTOPES.

By far the most important general result of these investigations is that, with the exception of hydrogen, the weights of the atoms of all the elements measured, and therefore almost certainly of all elements, are whole numbers to the accuracy of experiment. With the mass-spectrograph, this accuracy is generally one part in a thousand. Of course, the error expressed in fractions of a unit increases with the weight measured, but with the lighter elements the divergence from the whole number rule is extremely small.

This enables the most sweeping simplifications to be made in our ideas of mass. The original hypothesis of Prout, put forward in 1815, that all atoms were themselves built of atoms of " protyle," a hypothetical element which he tried to identify with hydrogen, is now re-established, with the modification that the primordial atoms are of two kinds: Protons and electrons, the atoms of positive and negative electricity. The atom, as conceived by Sir Ernest Rutherford, consists essentially of a positively-charged central nucleus around which are set planetary electrons at distances great compared with the dimensions of the nucleus itself.

The chemical properties of an element depend solely on its atomic number, which is the charge on its nucleus expressed in terms of the unit charge, e. A neutral atom of an element of atomic number N has a nucleus consisting of $K + N$ protons and K electrons and around this nucleus are set N electrons. The total number of protons in the atom $K + N$ is called its *mass-number*. The weight of an electron on the scale we are using is 0·0005, so that it may be neglected. The weight of this atom will therefore be $K + N$, so that if no restrictions are placed on the value of K, any number of isotopes are possible.

A statistical study of the results given above shows that the natural restrictions can be stated in the form of rules as follows :—

(*a*) *In the Nucleus of an Atom there is never less than One Electron to every Two Protons.*—There is no known exception to this law. It is the expression of the fact that if an element has an atomic number N, the atomic weight of its lightest isotope cannot be less than 2N. True atomic weights corresponding exactly to 2N are known in the majority of the lighter elements up to argon (A^{36}). Among the heavier elements the difference between the weight of the lightest isotope and the value 2N tends to increase with the atomic weight; in the cases of mercury it amounts to 37 units.

(*b*) *The Number of Isotopes of an Element and their Range of Atomic Weight appear to have Definite Limits.*—So far the element with the largest number of isotopes determined with certainty is xenon, with seven, but the majority of complex elements have only two each. The maximum difference between the lightest and heaviest isotope of the same element so far determined is 8 units

in the cases of krypton and xenon. The greatest proportional difference, calculated on the lighter weight, is recorded in the case of lithium, where it amounts to one-sixth. It is about one-tenth in the case of boron, neon, argon and krypton.

(c) *The Number of Electrons in the Nucleus tends to be Even.*—This rule expresses the fact that in the majority of cases, even atomic number is associated with even atomic weight and odd with odd. If we consider the three groups of elements, the halogens, the inert gases and the alkali metals, this tendency is very strongly marked. Of the halogens—odd atomic numbers—all 6 atomic weights are odd. Of the inert gases—even atomic numbers 18 (+ 2 ?) are even and 3 odd. Of the alkali metals—odd atomic numbers—7 are odd and 1 even. In the cases of elements of other groups the preponderance, though not so large, is still very marked and beryllium and nitrogen are the only elements yet discovered to consist entirely of atoms the nuclei of which contain an odd number of electrons.

In consequence of the whole-number rule there is now no logical difficulty in regarding protons and electrons as the bricks out of which atoms have been constructed. An atom of atomic weight m is turned into one of atomic weight $m + 1$ by the addition of a proton plus an electron. If both enter the nucleus, the new element will be an isotope of the old one, for the nuclear charge has not been altered. On the other hand, if the proton alone enters the nucleus and the electron remains outside, an element of next higher atomic number will be formed. If both these new configurations are possible, they will represent elements of the same atomic weight, but with different chemical properties. Such elements are called "isobares" and are actually known—*e.g.*, the principal constituents of argon and calcium.

The case of the element hydrogen is unique ; its atom appears to consist of a single proton as nucleus with one planetary electron. It is the only atom in which the nucleus is not composed of a number of protons packed exceedingly closely together. Theory indicates that when such close packing takes place the effective mass will be reduced, so that when four protons are packed together with two electrons to form the helium nucleus, this will have a weight rather less than four times that of the hydrogen nucleus, which is actually the case. It has long been known that the chemical atomic weight of hydrogen was greater than one-quarter of that of helium, but so long as fractional weights were general there was no particular need to explain this fact, nor could any definite conclusions be drawn from it. The results obtained by means of the mass-spectrograph remove all doubt on this point, and no matter whether the explanation is to be ascribed to packing or not, we may consider it absolutely certain that if hydrogen is transformed into helium a certain quantity of mass must be annihilated in the process.

The theory of relativity indicates that mass and energy are interchangeable and that in C.G.S. units a mass m at rest may be expressed as a quantity of energy mc^2, where c is the velocity of light. Even in the case of the smallest mass this energy is enormous. If instead of considering single atoms we deal with quantities of matter in ordinary experience, the figures for the energy become prodigious. Take the case of 1 gram-atom of hydrogen—that is to say, the quantity of hydrogen in 9 c.c. of water. If this is entirely transformed into helium the energy liberated will be $0{\cdot}0077 \times 9 \times 10^{20} = 6{\cdot}93 \times 10^{18}$ ergs. Expressed in terms of heat this is $1{\cdot}66 \times 10^{11}$ calories or, in terms of work, 200,000 kilowatt hours. The transmutation of the hydrogen from 1 pint of water would liberate sufficient energy to drive the *Mauretania* across the Atlantic and back at full speed.

Should the research worker of the future discover some means of releasing this energy in a form which can be employed, the human race will have at its command powers beyond the dreams of scientific fiction ; but the remote possibility must always be considered that the energy once liberated will be completely uncontrollable and by its intense violence detonate all neighbouring substances. In this event the whole of the hydrogen on the earth might be transformed at once and the success of the experiment published at large to the universe as a new star.

VERIFICATION OF THE THEORY OF RELATIVITY.

By Sir Frank Dyson, F.R.S., Astronomer Royal.

In order to explain the transmission of the undulations of light across space, the existence of a medium called " ether " was assumed. This was supposed to possess properties such as rigidity and elasticity similar to those of matter. When it was found that electro-magnetic oscillations (such as we now have in radio-telegraphy) were transmitted with the same velocity as light, the same all-pervading medium was naturally taken as their home.

Many noteworthy attempts have been made to determine by optical and electrical means the movement of the earth through this medium. They all gave negative results, and in explanation Einstein put forward in 1905 the restricted theory of relativity. This theory reviewed our fundamental ideas of time and space; it denied the existence of absolute space and absolute time, but regarded these as dependent on the observer. Einstein showed that a simple relationship held between the measures of space and time made by two observers moving uniformly with respect to each other. This theory was in harmony with the experimental results which had failed to discover the motion of the earth through the ether, and also accounted for the change of mass found by experiment in particles moving with very great velocities.

In 1908 Einstein's theory was put in a clearer light by Minkowski, who introduced the idea of the *continuum*. Events take place in a four-dimensional *continuum* of space and time and not in a three-dimensional space and a wholly independent one-dimensional time. The relationship between the space and time of two observers moving relatively to one another was shown to be analogous to a rotation of axes in ordinary Euclidian geometry.

Einstein's Law of Gravitation.

So far, the theory of relativity had applied only to systems in uniform motion relatively to one another. Could it be extended to systems in which there is accelerated motion? In Newtonian dynamics acceleration is attributed to force. Centrifugal force is regarded as a fictitious kind of force attributable to the rotation of the system of reference, but "gravitational" force as something inherent in matter. Is it possible to explain the latter by the properties of the *continuum?* By an extraordinarily brilliant piece of mathematical analysis, Einstein was led to formulate in 1915 a law of gravitation. In the neighbourhood of matter the geometry of the *continuum* differed slightly from that of Euclid. It is not possible to visualise this, but it is analogous to the difference, in two-dimensional geometry, between the surface of a large sphere and a plane. The non-Euclidian propraties of the *continuum* manifest themselves as a field of force. This can be illustrated in principle by the deflexion of path undergone by a pedestrian who tries to walk in a straight course over the slope of a hill. The deflexion is due to the geometrical properties of the slope which may be regarded as a non-Euclidian space of two dimensions.

Einstein's law of gravitation, though entirely different from Newton's in mathematical form as in the ideas from which it arose, gives results almost identical with those of Newton. This is its first merit, for Newton's law of the inverse square has been found sufficient to explain in great detail the movements of sun, moon and planets, precession of the equinoxes, the tides, the figure of the earth and many other phenomena. To the first order, then, Einstein's law gives results identical with those of Newton. But there is one phenomenon which has puzzled astronomers since the time of Leverrier. The planet Mercury moves round the sun in an orbit which is, to a first approximation, an ellipse. But closer study shows that the position of this ellipse undergoes a change in the course of time, so that the point at which Mercury is nearest the sun (its perihelion) is not fixed, but is slowly revolving. The greater part of this revolution is duly explained by the attraction of the other planets, but a part is left over—only 40 seconds of arc a century—which had not been satisfactorily accounted for, although numerous hypotheses had been framed. Einstein's law of gravitation took this discrepancy in its stride and accounted for it exactly.

The Bending of Light Rays.

This was an achievement which greatly enhanced the probability of Einstein's law being correct. He accordingly examined it to see if there were other phenomena which would follow from his law, but were not given by that of Newton. He found two. The first of these relates to the bending of light. If light in its

journey to the earth from a star passes near the sun, it will be slightly deflected in its course, just as a particle of matter would be. He gave the exact amount of this deflexion, which is greater the nearer the light passes by the sun. This prediction was verified at the total eclipse of the sun on May 29th, 1919. British expeditions were sent to Brazil and to the west coast of Africa to photograph the eclipsed sun. Seven photographs were taken which showed a number of stars. The observers in Brazil waited for two months, when they were able to photograph the same stars just before sunrise, and the photographs were brought home and carefully measured. It was found that the relative position of the stars had been slightly changed in accordance with Einstein's prediction.

The differences in the relative positions of the stars are, of course, not visible to the eye, as they are very minute. The largest displacement is only one-third of the diameter of the star's image shown on the photograph.

The predicted amount of the bending of the light by the sun's gravitation for the stars shown on one of the photographs taken is compared in the following table with the amount actually observed :—

Predicted.	Observed.
0·32″	0·20″
0·33	0·32
0·40	0·56
0·53	0·54
0·75	0·84
0·85	0·97
0·88	1·02

The observers in Africa were not so fortunate in weather conditions as those in Brazil, but they nevertheless succeeded in verifying Einstein's prediction. At the total solar eclipse of 1922 these results were confirmed by Canadian and Australian and still more by American astronomers.

Displacements in the Solar Spectrum.

Another test which Einstein proposed for the verification of his theory is a slight displacement in position of the lines in the solar spectrum. The exact position of a line in a spectrum may be considered as measuring the time of some particular vibration in the atoms of the substance the light of which is being analysed. According to the theory of relativity, the time of vibration of an atom in the sun will be lengthened slightly by the effect of gravitation. If, then, the position of the iron lines in the solar spectrum, due to iron vapour, for example, are compared with the position of those arising from the light of an electric arc with iron poles, they should be found to be shifted very slightly towards the red end of the spectrum.

The verification of this consequence of the theory of relativity was a matter of considerable difficulty, because there are many causes which produce slight displacements in spectral lines. Of these the effects due to possible movements of the solar gases were the most difficult to eliminate. Motion effects due to the sun's rotation and to the earth's rotation and varying distance from the sun are well understood, and could readily be allowed for. There was, however, a puzzling difference in the displacement in different parts of the sun's disc, the observed shift of the lines increasing from the centre towards the solar limb, where it was found to be in excess of Einstein's prediction. To determine the cause of this involved measuring the shift in light coming from the hidden face of the sun, as reflected to us by the planet Venus when near superior conjunction (behind the sun).

In addition to effects due to motion, the positions of spectrum lines also depend to a small extent on the pressure and on the electrical conditions of the gas from which the light comes, and on the effects of anomalous refraction if the gases have an appreciable density. This complicated problem was attacked by several astronomers.

Mr. J. Evershed, the Director of the Indian Observatory at Kodaikanal, found that the lines in the solar spectrum did, in fact, show a displacement, and he came to the conclusion that this displacement was for the greater part that predicted by Einstein, the disturbing effects, due to pressure, &c., being negligible according to his researches. His conclusion has since been confirmed in a very complete manner by Dr. St. John, of the Mount Wilson Observatory, who has not only verified the relativity prediction, but has given an explanation of some shifts of the lines in excess of the Einstein effect. These residual effects had also been noticed by Evershed.

THE INTERIOR OF A STAR.*

By Prof. A. S. Eddington, F.R.S.

Dimensions of a Star.

On December 13, 1920, the angular diameter of a star was measured for the first time in history with an apparatus devised by Prof. A. A. Michelson. Hitherto every star had appeared as a mere point of light, and no test had been able to differentiate it from a geometrical point. But on that eventful evening a 20-ft. interferometer constructed at the Mount Wilson Observatory was turned on the star Betelguese, and the measurement revealed that this star had a disc one-twentieth of a second of arc in diameter—about the size of a halfpenny 50 miles away. The distance of Betelgeuse is known roughly (unfortunately it cannot be found so accurately as the distance of many stars), so that we can convert this apparent size into approximate actual size. Betelgeuse is not less than 200 million miles in diameter. The orbit of the earth could be placed entirely inside it.

The stars are thus not limited to objects of comparatively small bulk like the sun; there are among them individuals truly gigantic in comparison. We can add another step to the astronomical multiplication table – a million earths make one sun; ten million suns make one Betelgeuse. This is a comparison of volume, not of amount of material. It leaves open the question whether in order to obtain one of these giants we should take the material of ten million suns rolled into one, or whether we should take the material of the sun and inflate it to ten million times its present size.

There is no doubt that the latter answer is nearer the truth. Betelgeuse contains more matter than the sun (perhaps fifty times as much); but in the main its vast bulk is due to the diffuseness

---

* Abstracted from a discourse delivered before the Royal Institution on February 23, 1923.

with which this material is spread out. It is a great balloon of low density, much more tenuous than air, whereas in the sun the material is compressed to a density greater than water.

Whether a star is one of these balloon-like bodies or whether it is dense like the sun depends on the stage of its life at which we catch it. It is natural to think that the stars gradually condense out of diffuse material, so that they become denser and denser as their life history proceeds. We can now see in the heavens samples of every stage in the development of a star. The majority of those seen with the naked eye are in the early diffuse state; that is not because these young stars are really more numerous, but because their great bulk renders them brighter and more conspicuous. What I shall have to say about the inside of a star refers chiefly to the young diffuse stars—the "giant stars" as they are called. The reason is that we understand much more about the properties of matter when it is in the condition of a perfect gas than when it is condensed; although the difficulties of treating a dense star like the sun are not insuperable, we have naturally made the most progress with the easier problem of giant stars.

Internal Temperatures.

We only observe the physical conditions of the surface of a star, and at first it might seem impossible to learn anything about the conditions in the interior. Consider for example, the question of temperature. The nature of the light received from Betelgeuse teaches us that the temperature is 3,000° C.—not an extravagantly high temperature judged even by terrestrial standards. But this refers, of course, to the layer near the surface from which the observed light is coming; it is just the marginal temperature of the furnace, affording no idea of the terrific heat within.

The internal temperature of a star depends on the particular star considered, but it is generally from 2 to 20 million degrees at the centre. Do not imagine that this is a degree of heat so vast that ordinary conceptions of temperature have broken down. These temperatures are to be taken quite literally. Temperature is a mode of describing the speed of motion of the ultimate particles of matter. In a mass of helium at ordinary temperatures the average speed of the atoms is rather less than 1 mile per second; at 4 million degrees it is 100 miles per second. This is a high speed, but not a speed to feel uncomfortable over. In the laboratory physicists experiment with atoms of helium, the α-particles from radio-active substances, moving at 100,000 miles a second. The physicists are rather disappointed with the jog-trot atoms in the stars.

Material and Ethereal Heat.

We must imagine, then, a typical giant star as a mass of material with average density about that of air swollen to at least

a thousand times the bulk of the sun. The atoms of which it consists are rushing in all directions with speeds up to 100 miles a second, continually colliding and changing their courses. Each atom is being continually pulled inwards by the gravitation of the whole mass, and as continually boosted out again by collision with atoms below. The energy of this atomic motion, which we may term "material heat," constitutes a great store of heat contained in the star; but this is only part of the store. The star contains a store of another kind of heat, "ethereal heat," or ether-waves like those which bring to us the sun's heat across 90 million miles of vacant space. These waves also are hastening in all directions inside the star. They are encaged by the material, which prevents them leaking into outer space except at a slow rate. An ether-wave making for freedom is caught and absorbed by an atom, flung out in a new direction, and passed from atom to atom; it may thread the maze for hundreds of years until by accident it finds itself at the star's surface, free now to travel through space indefinitely, or until it ultimately reaches some distant world, and perchance entering the eye of an astronomer makes known to him that a star is shining.

The possession of this double store of heat is a condition which we do not encounter in any of the hot bodies more familiar to us. In the hot bodies of the laboratory the heat is almost entirely in the material form, the ethereal portion being insignificant. In the giant stars the heat is divided between the two forms in roughly equal amounts. Can we not imagine a third condition in which the heat is almost wholly ethereal, the material portion being insignificant? We can imagine it, no doubt; but the interesting, and perhaps significant, thing is that we do not find it in Nature.

Pressure of Light in a Star.

You have heard of the pressure of light—that light actually has mass and weight and momentum, and exerts a minute pressure on any object which obstructs it. A beam of light or ether waves is like a wind, a very minute wind as a rule; but the intense ethereal energy inside the star makes a strong wind. This wind distends the star. It bears to some extent the weight of the layers overhead, leaving less for the elasticity of the gas to bear. That of course has to be taken into account in our calculation of the internal temperatures—making them lower than the older theory supposed.

Just as ether and matter share the heat-energy between them, so the ethereal wind and the material elasticity share the burden of supporting the weight of the layers above, and we are able to calculate the proportions in which they share it. To a first approximation the same proportion holds throughout nearly the whole interior, and the proportion depends only on the total

mass of the star, not on the density or even on the chemical composition of the material. Moreover, in order to make this calculation we do not need any astronomical knowledge; all the constants in the formula have been determined by the physicist in his laboratory.

Let us imagine a physicist on a cloud-bound planet, who has never heard tell of the stars, setting to work to make these calculations for globes of gas of various dimensions. Let him start with a globe containing 10 gm., then 100 gm., 1,000 gm., and so on. The globes mount up in size rather rapidly. No. 1 is about the weight of a letter; No. 5, a man; No. 8, an airship; No. 10, an ocean liner; after that comparisons are difficult to find. The following table gives part of his results:—

No. of Globe.	Ethereal Pressure.	Material Pressure.
30	0·00000016	0·99999984
31	0·000016	0·999984
32	0·0016	0·9984
33	0·106	0·894
34	0·570	0·430
35	0·850	0·150
36	0·951	0·049
37	0·984	0·016
38	0·9951	0·0049
39	0·9984	0·0016
40	0·99951	0·00049

The early part of the table would consist of long strings of 0's and 9's. For the 33rd, 34th and 35th globes the table gets interesting; and then lapses back into 9's and 0's again. Regarded as a tussle between ether and matter to control the situation, the contest is too one-sided to be interesting, except just from Nos. 33 to 35, where something more exciting may be expected.

Now let us draw aside the veil of cloud behind which our physicist has been working, and let him look up into the skies. He will find there a thousand million globes of gas all of mass between the 33rd and 35th globes. The lightest known star comes just below the 33rd globe; the heaviest known star is just beyond the 35th globe. The vast majority are between Nos. 33 and 34, just where the ethereal pressure begins to be an important factor in the situation.

It is a remarkable fact that the matter of the universe has aggregated primarily into units of nearly constant mass. The stars differ from one another in brightness, density, temperature, etc., very widely; but they all contain roughly the same amount of material. With a few exceptions they range from half to five times the mass of the sun. There can no longer be serious doubt as to the general cause of this, although the details of the explanation may be difficult. Gravitation is the force which condenses matter; it would if unresisted draw more and more matter

together, building globes of enormous size. Against this, ethereal pressure is the main disruptive force (doubtless assisted by the centrifugal force of the star's rotation): its function is to prevent the accumulation of large masses.

This resistance, as we see, only begins to be serious when the mass has already nearly reached the 33rd globe, and if indeed it is efficacious, it will stop the accumulation before the 35th globe is reached, because by then it has practically completely ousted its more passive partner (material pressure). We do not need to know exactly how strong the resistance must be in order to prevent the accumulation, because when once the resistance begins to be appreciable it increases very rapidly, and will very soon reach whatever strength is required. All over the universe the masses of the stars bear witness that the gravitational aggregation proceeded just to the point at which the opposing force was called into play and became too strong for it.

Ascending and Descending Temperature Stages.

It was shown by Homer Lane in 1870 that as a gaseous star contracts its temperature will rise. Betelgeuse is typical of the first stage when the temperature has risen just far enough for the star to be luminous. It will go on contracting and becoming hotter, its light changing from red to yellow and then to white. When the condensation has proceeded far enough, the material, if it behaves like terrestrial substances, will become too dense to follow the laws of a perfect gas. A different law then begins to take control. The rise of temperature becomes less rapid, is checked, and finally the temperature falls. We can calculate that the greatest temperature is reached at a density of about one-quarter to one-third of that of water. The sun is denser than water, so that, according to this theory, it must have passed the summit and is in the stage of falling temperature.

So long as the temperature is rising, the brightness of the star scarcely changes. It is becoming hotter but smaller. Calculation shows that the increased output of light and heat per square metre of surface, and the decreased area of the surface, very nearly counteract one another, so that the total output remains fairly steady. But on the downward path the falling temperature and diminishing surface both reduce the light, which falls off rapidly between the successive stages or types which we recognise. That is entirely in accordance with what is observed to happen.

Taking any level of temperature, a star will, in its life-history, pass through it twice, once ascending and once descending. In the main we have been in the habit of classifying stars according to their surface temperature, because it is on this that the spectral characteristics of the light, its colour and the chemical elements revealed, chiefly depend. But that classification mixes together

stars from an early ascending stage and those from a later descending stage. For example, a star like Betelgeuse, just beginning its career, is put in the same class with a dense red star, which has run its course and reached its second childhood. They are both red stars of low temperature, and that was good enough for the early attempts at classification. Sir Norman Lockyer always stoutly maintained the existence of the ascending and descending series, but he was almost alone among spectroscopists in this. He did not actually succeed in separating the ascending and descending stars, though sometimes he came very near to the right criterion. We owe to Russell and to Hertzsprung the actual separation. They discovered it not by spectroscopy, but by measuring the absolute brightness of stars ; the greater brightness of the ascending stars, due to their large bulk, easily distinguishes them from the descending stars, at any rate in the low temperature groups. At the highest temperatures the two series merge into one another.

Recently, however, some new results have confronted us which seem to call for a considerable modification of the theory of stellar evolution just described. It appears that even when the density of a star is greater than water, the material does not cease to behave as a perfect gas. The reason is that at the very high temperature in the interior, the atoms are broken up (highly ionised) ; the remnants occupy much less volume than terrestrial atoms and can be compressed much closer together. Both theory and observation indicate that in some of the stars we are dealing with material denser than anything observed on the earth, which is nevertheless perfectly compressible like an ideal gas.

Atoms and Electrons in the Interior of the Star.

We have hitherto pictured the inside of a star as a hurly-burly of atoms and ether waves. We must now introduce a third population to join in the dance. There are vast numbers of free electrons—unattached units of negative electricity. More numerous than the atoms, the electrons dash about with a hundredfold higher velocity, corresponding to their small mass, which is only about $\frac{1}{1800}$ of a hydrogen atom. These electrons have come out of the atoms, having broken loose at the high temperature here involved ; and in a typical star a large proportion of them must have become free.

This condition solves for us our chief difficulty as to the molecular weight of stellar material, which we must know in order to perform our calculations as to the state of the star. At first sight it might seem hopeless to arrive at the molecular weight without knowing the elements which constitute the bulk of the material. But suppose first that the temperature is so high that all the satellite electrons, which are believed to be revolving about

the composite central nucleus of any atom, have broken away. An atom of sodium will have separated into 12 particles, viz., 11 electrons and 1 mutilated atom; its atomic weight 23 is divided between 12 independent particles, so that the average weight of each is $23/12 = 1 \cdot 92$. Next take iron; the atomic weight 56 is divided between 27 particles: average $2 \cdot 07$. For tin we have 119 divided by 51: average $2 \cdot 34$. For uranium 238 divided by 93: average $2 \cdot 56$. It scarcely matters what element we take; the average weight of the ultimate particles (which is what we mean by the molecular weight) is always somewhere about 2. If only the stars were a bit hotter than they actually are it would make our task very easy. Unfortunately they are not hot enough to give complete separation, and the actual degree of separation will depend on the temperature of the star, thus introducing a difficult complication. Generally at least half the electrons are detached, and the molecular weight must be taken between 2 and 3.

Brightness and Mass.

We pictured a physicist on a cloud-bound planet who was able from laboratory data to predict how large would be the masses into which the material of the universe must aggregate. Let us now set him a harder task. We inform him that we have observed these masses of gas, and, choosing one equal, say, to his 34th sphere, we ask him to predict how brightly it will shine. As already mentioned, the star keeps practically the same brightness so long as it is a perfect gas ascending in temperature; so it should not be necessary to give the physicist any data except the precise mass. To use the same plan as before, we imagine a series of lamps of 10 candle-power, 100 candle-power, 1,000 candle-power, and so on; and his task is to pick out which lamp in this series corresponds approximately to the star. I believe that it is now possible for him to perform this task, and to pick out (correctly) the 31st lamp. For this purpose, however, it is not enough that he should know all about the heat stored in the interior of the star; the brightness of the star depends on the rate at which the ether waves are leaking out, and that introduces a new subject—the obstructive power of the material atoms which dam back the radiant flow.

Another name for this obstructive power is *opacity*. A substance which strongly obstructs the passage of light and heat waves is said to be opaque. The rising temperature towards the centre of the star urges the heat to flow outwards to the lower temperature level; the opacity of the material hinders this flow. The struggle between these two factors decides how much light and heat will flow out. We have calculated the internal temperature distribution, so that we know all about the first factor; if, then, we can observe the outward flow which occurs, that should

settle the value of the second factor—the opacity. The outward flow is capable of observation, because it constitutes the heat and light sent to us by the star.

One of the troubles of astronomy is that our information about the stars is so scattered. We know the mass of one star very accurately, but we do not know its absolute brightness; we know the brightness of another, but not its mass; for a third we may have an accurate knowledge of the density, but nothing else. For Sirius, Procyon and α Centauri our knowledge is fairly complete and accurate; but none of these are giant stars in the state of a perfect gas and they are therefore useless for the present discussion. Within the last year or so, however, we have been so fortunate as to obtain complete and very accurate information for one of the giant stars, Capella. This is another of the benefits which astronomy has derived from Prof. Michelson's interferometer method of observation. The brighter component of Capella (which is a double star) has a mass 4·2 times that of the sun, and a luminosity 160 times greater. We can use these facts to calculate the opacity of Capella, and it turns out to be 150 in C.G.S. units. To illustrate the meaning of this, let us enter Capella and find a region where the density is that of the terrestrial atmosphere we are accustomed to; a slab of this gas only 6 inches thick would form an almost opaque screen. Only 1/20th of the radiant energy falling on one side would get through to the other, the rest being absorbed by the gas.

Absorption of Ether Waves.

It seems at first surprising that 6 inches of gas should stop the ether waves so effectually, but we might have anticipated something like this from general physical knowledge. We give different names to ether waves according to their wave-lengths. The longest are the Hertzian waves used in wireless telegraphy; then come the invisible heat waves, then light waves, then photographic or ultra-violet waves. Beyond these we have X-rays, and finally—the shortest of all—the γ-rays emitted by radio-active substances. Where in this series are we to place the ether waves in the interior of a star, which constitute its ethereal heat? It is solely a question of temperature, and the ether waves at stellar temperatures are those which we call X-rays—more precisely, they are very "soft" X-rays. Now X-rays, and soft X-rays especially, are strongly absorbed by all substances, and the opacity which we have found in Capella is of the same order of magnitude as the opacity of terrestrial substances to X-rays measured in the laboratory.

The physicist in the laboratory, investigating the opacity of substances to soft X-rays, has a big advantage, however, because he can vary the material experimented on, whereas we have to be content with the material, whatever it is, composing the stars.

The physicist is also interested in finding how the absorption changes for different wave-lengths. We can follow him in this, and even do better than he, because he is restricted by certain practical difficulties to a narrow range of wave-length, whereas we can explore a range of wave-length covering a ratio of at least 10 to 1 by using stars of different temperatures. It is true that our results are not yet very accurate; we have only one star, Capella, for which a really good determination is possible, but for other stars rough values can be found. The terrestrial results indicate an extremely rapid change of absorption for slight alterations of wave-length; the astronomical results, on the contrary, give a nearly steady absorption-coefficient. We cannot yet detect certainly whether it increases or decreases with wave-length, but, at any rate, there is no very rapid change. This profound discrepancy between astronomical and laboratory results leads us to inquire more deeply into the theory of absorption in a star.

It is now generally agreed that when ether-waves fall on an atom they are not absorbed continuously. The atom lies quiet, waiting its chance, and then suddenly swallows a whole mouthful at once. The waves are done up in bundles called "quanta," and the atom has no option but to swallow the whole bundle or leave it alone. Generally the mouthful is too big for the atom's digestion, but the atom does not stop to consider that. It falls a victim to its own greed—in short, it bursts. One of its satellite electrons shoots away at high speed, carrying off the surplus energy which the atom was unable to hold. The bursting could not continue indefinitely unless there were some counter-process of repair. The ejected electrons travel about, meeting other atoms; after a time a burst atom meets a loose electron under suitable conditions, and induces it to stay and heal the breach. The atom is now repaired and ready for another mouthful as soon as it gets the chance.

From this cause a big difference arises between absorption of X-rays in the laboratory and in the stars. In the laboratory the atoms are fed very slowly; the X-ray bundles which they feed on can only be produced by us in small quantities. Long before the atom has the chance of a second bite it is repaired and ready for it. But in the stars the intensity of the X-rays is enormous; the atoms are gorged and cannot take advantage of their abundant chances. The consumption of food by the hungry hunter is limited by his skill in trapping it; the consumption by the prosperous profiteer is limited by the strength of his digestion. Laboratory experiments test the atom's skill in catching food; stellar experiments test how quickly it recovers from a meal and is ready for another. This accounts for the different opacity of stars, as compared with the opacity of terrestrial substances to ether waves.

Some of the leading factors participating in the problem of the interior of a star have now been discussed, and it is clear that many varied interests are involved. The partial results already attained, however, correspond well enough with what is observed to encourage us to think we have begun at the right end in disentangling the difficulties, and we do not anywhere come against difficulties which appear likely to be insuperable. The fact is that gaseous matter at very high temperature is the simplest kind of substance for a mathematical physicist to treat. To understand all that is going on in the material of a piece of wood is a really difficult problem, almost beyond the aspirations of present-day science ; but it does not seem too sanguine to hope that in a not too distant future we shall be able to understand fully so simple a thing as a star.

THE ORIGINS OF WIRELESS.

By Sir Richard Glazebrook, K.C.B., F.R.S.

In seeking the originators of radio-communication, the men who discovered electricity and investigated its fundamental properties are apt to be overshadowed by those who are concerned rather with the development of the art as we know it to-day. Many would be content to mention the names of Hertz, who in 1887 first produced and measured the wireless waves predicted twenty years earlier by Clerk Maxwell; of Lodge, who a year later showed at the Royal Institution some of its effects; of Marconi, whose inventions have done so much to forward its practical use; and of Fleming, who first investigated the properties of the rectifying valve.

These are great names in the growth of radio-communication, but tribute should also be paid to those who made this growth possible. To find them we must go back many years—centuries in some cases—to investigators who, driven by their love of discovery and impelled by their thirst to know, sought, not to discover wireless telegraphy, but to improve our knowledge of Nature and to bring under the realm of law and order some of the strange happenings which their searches led them to note.

Amber, found chiefly on the shores of the Baltic Sea, was much sought for in early days; recently an interesting dissertation on the trade routes of the ancient world has been written based on the dispersion of amber. About 600 B.C. it had reached Asia Minor, and Thales of Miletus is said to have been the first to observe its property of attracting light bodies to itself when rubbed. Thus we derive the name "electricity" (ἤλεκτρον = amber).

It was probably at a later date than this that the curious property of a stone found in Magnesia was first noted, at any rate in the Western world, when it was observed that if freely suspended it always set itself in a definite direction. It gained the name of the leading stone or loadstone, and this property formed the basis

of the science of magnetism. Tradition tells us that the Chinese knew of this property centuries earlier.

Modern knowledge both of electricity and magnetism dates from Dr. Gilbert, of Colchester, Physician to Queen Elizabeth, who in 1600 published his great and interesting work "De Magnete." Gilbert studied only electricity produced by friction; the electric current was still unknown, and for nearly 200 years remained unknown until Galvani, at Bologna in 1786, observed the convulsive shock produced in a frog's leg—at first when it was connected to a frictional electrical machine, and then later when two dissimilar metals, iron and copper, were placed in contact with nerve and muscle respectively and were then made to touch. His observations were continued and extended by Volta at Pavia, who showed in 1800 that the electricity originated at the contact of the metals. This led him to the discovery of the voltaic pile and the construction of an electric battery.

Various workers from Gilbert onwards had surmised that there must be some relation between electricity and magnetism. The verification of this was due to Oersted, Professor at Copenhagen, who in 1820 showed that a wire carrying a current held near a magnet caused the magnet to move. Oersted's great discovery was at once repeated by Ampère in Paris, and he, by the aid of a few brilliant fundamental experiments, discovered the laws which govern the mutual reaction between a current and a magnet. About the same time Faraday, at the Royal Institution in London, pursued the matter still further, and laid the foundations of the science of electro-magnetism, the basis of all electro-technical applications of to-day.

Meanwhile in Germany G. S. Ohm was at work. Volta had shown in 1800 that electrical force or "electro-motive force" was produced in his battery, and that when the two metals which constitute its two poles are joined by a wire, a current of electricity flows round the circuit. It was left for Ohm to state the relation between the current, the electro-motive force—or electrical pressure—producing it and the resistance of the circuit. Meanwhile, in America, Joseph Henry had during the same period discovered for himself many of the fundamental laws of electromagnetism.

These men, scattered throughout many lands, yet inspired by the same end—the improvement of natural knowledge—were the founders of modern electricity. When, therefore, some sixty years ago, a body of English men of science, led by Lord Kelvin, realised that the time had come to consolidate their knowledge into a system of accurate measurement, they found that new ideas needed definition, new units and standards required names, and with one consent they agreed to give to these standards the names of the great men whose labours through the centuries had wrested from Nature the secrets of electricity and magnetism. Thus we

have the ohms and volts, amperes, henrys and farads which now form part of our daily language.

On the work of the men whose names are thus commemorated is based the discoveries of the brilliant experimenters who have made it possible to girdle the earth with a wireless chain depending on two or at most three great stations.

Foremost among those associated with modern developments is Clerk Maxwell, who in 1865 read before the Royal Society his paper on "The Equations of the Electro-Magnetic Field." It was an attempt, which has stood the test of time, to apply mathematical reasoning to those principles, enunciated by Faraday, on which the construction of generators and motors, transformers and, indeed, practically all electric machinery, is based. This reasoning led him to the result that the effect of changes in an electric current in a conducting wire would be propagated through space with a speed depending on the two constants, inductive capacity and magnetic permeability, which define the electric and magnetic conditions of the medium surrounding the wire. The values of these constants for air can be found from electrical considerations, and hence the velocity with which electro-magnetic disturbances are propagated can be calculated. To quote Maxwell's words :—

"We now proceed to investigate whether these properties of that which constitutes the electro-magnetic field, deduced from electro-magnetic phenomena alone, are sufficient to explain the propagation of light through the same substance," and his conclusion is: "The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electro-magnetic disturbance propagated through the field according to electro-magnetic laws."

Maxwell found that when the calculations were made, the resulting value for the velocity was approximately equal to the velocity of light. The work was extended in his "Treatise on Electricity and Magnetism," published in 1873. The values of the velocity of light and the velocity of propagation of electro-magnetic waves were not known then with present-day accuracy, and he concludes that they are quantities of the same order of magnitude. Present-day figures show that they are identical, and the electro-magnetic theory of light is universally accepted. Nor was the result true only for propagation through air or inter-stellar space; such observations as were then available showed that, in all probability, it held for all transparent media, though there were discrepancies, known now to be due to dispersion, which required explanation. But there was a wide gap between this theoretical deduction of Maxwell and the wireless telegraphy of to-day, which needed many more investigations in "pure" science before the bridge was complete. No one had received electro-magnetic vibrations—at any rate, to his certain knowledge. The method of generating them and the means for measuring them were still to come.

For the former we have to go back to a remarkable paper of 1853 by Lord Kelvin. Helmholtz seems to have been the first to conceive that the discharge of a condenser through a wire might consist of a forward and backward motion of electricity between the coatings—a series of currents in opposite directions. Lord Kelvin took up the question mathematically and investigated the phenomena. He showed that, under certain conditions, there would be oscillations of periodic time $2\pi\nu LC$, where L is the inductance of the coil, and C the capacity of the condenser. These oscillations must, according to the theory, give rise to waves travelling out into space with the electro-magnetic velocity. Fitzgerald had predicted in 1883 that they might be produced by utilising the oscillatory discharge of a leyden jar, and Sir Oliver Lodge in 1887 produced and detected them. For their detection the principle of resonance was employed. Any mechanical system free to vibrate has its own period of oscillation, and the application to it of a series of small impulses at intervals coincident with the free period of the system results in a disturbance of large amplitude. So, too, an electric system having capacity and inductance has its own period of electrical oscillation, and, if this coincides with the period of incoming electrical waves, electrical disturbances of a magnitude which can be detected by our apparatus are set up. It is necessary that the receiver and the transmitter should be in tune. Lodge made use of this principle, and, by receiving the waves on wires adjusted to resonance with his leyden jar and coil, was able to detect them. David Hughes, working in the early 'eighties, had already detected such oscillations, but was discouraged from pursuing the subject.

In 1879, in consequence of the offer of a prize by the Berlin Academy, the attention of Heinrich Hertz, then a student under Helmholtz, was attracted to the problem of electric oscillations and their detection. He came to the conclusion that with the means of observation then at his disposal "any decided effect could scarcely be hoped for, but only an action lying just within the limits of observation." The investigation was laid aside, only to be revived in 1886 by a chance observation of the effect of resonance in two circuits which happened to be in tune, and his realisation of the fact that herein lay the means of solution of his problem. His paper "On Very Rapid Electric Oscillations" appeared in 1887, and from this experiment came verification of Maxwell's theory, the basis of all our knowledge of wireless. Fitzgerald directed the attention of English physicists to the work at the British Association meeting in 1888, and Lodge exhibited many of the effects of the waves at the Royal Institution in 1889.

The investigations which led to such brilliant results were inspired by the desire for knowledge; the idea of their practical application was entirely absent. Signalling by wireless waves

was not foreshadowed until Crookes suggested it in 1892, and in 1893 Lodge heard of Branly's coherer and applied it to the rectification and reception of wireless waves. From this started the investigations of many of those whose names as pioneers are familiar to all. But another discovery in pure science was necessary to complete the work.

Edison had shown in 1883 that if an insulated electrode is inserted in an ordinary glow lamp, there is a current of negative electricity from the filament to the electrode, and Fleming made some observations about this date on the Edison effect. In 1904 he applied them to produce a valve rectifier for high-frequency oscillations by connecting one pole of his receiving circuit to an insulated plate or cylinder within a carbon lamp, of which the negative electrode formed the other pole of the receiving circuit.

Dr. Lee de Forest improved this oscillation valve a little later, making it an amplifier as well as a rectifier by placing between the filament and the plate or cylinder a grid of metal wire connected to an external source of electromotive force. There is ordinarily a current of negative electricity passing from the filament to the plate— the plate current it is called—through the interstices of the grid. By varying the potential of the grid this current can be varied, and the conditions can be so adjusted that small changes in the potential of the grid will produce large changes in the plate current. The grid is connected to one pole of the circuit receiving the incoming waves, and the small variations of potential which they produce thus give rise to large variations of the plate current. These can be made to actuate a telephone and thus to produce audible sounds. By placing a number of valves in series, very large amplifications are possible.

The other uses of the valve are numerous. It is employed as a transmitter for wireless work, while it finds many applications as a source, or rather regulator, of vibrations of comparatively short period. The Post Office has used it as an amplifier of speech, while Mr. F. E. Smith has applied it as a source of sound in connection with the measurement of audibility.

The whole of this arose from Edison's observation of the discharge of negative electricity from the heated filament, but its development may be said to have been dependent on another and more fundamental discovery about 1897—that of the existence of the electron, which we owe to Sir J. J. Thomson.

Before the introduction of the oscillation or thermionic valve, as it is sometimes termed, radio-communication was in practice confined to telegraphy. Signals were sent out and received which were interpreted by the use of the Morse code. The advent of the thermionic valve has made wireless telephony, with its recent remarkable development in the form of broadcasting, a practical proposition and a factor of interest in the lives of innumerable people.

THERMIONIC VALVES.*

By Prof. J. A. Fleming, F.R.S., Professor of Electrical Engineering in the University of London.

Early Discoveries.

The history and development of the thermionic valve is a striking example of the important industrial applications that sometimes follow from discoveries which take place in the course of purely scientific researches. In 1883 Edison sealed a metal plate into the ordinary electric incandescent lamp between the legs of its carbon filament. This plate was carried on a wire sealed through the wall of the glass bulb. He noticed that when the filament was made incandescent by a direct current sent through it, simultaneously a small electric current could be detected in a circuit between the *positive* terminal of the filament and the wire carrying the metal plates; on the other hand, no current could be detected between the *negative* end of the filament and the plate. This phenomenon was called the "Edison effect," but no explanation of it was given by its discoverer, nor was any practical use made of it at the time.

Investigations on the nature of the Edison effect undertaken by the writer in 1883 and onwards showed that the effect was connected with the projection in straight lines of particles from the filament; further, these projected particles carried a charge of negative electricity and could convey negative electricity from the filament to the plate, but not in the opposite direction. A further step in advance was made about 1897 by Sir Joseph Thomson, who showed that the chemical atoms of matter, which at the time were thought to be incapable of being divided, contained still smaller atoms of electricity, now called *electrons.* Soon afterwards, it was ascertained that the incandescent filament of the ordinary electric lamp is a prolific and continuous source of electrons, which are sent out in all directions.

*** Abstracted from Pamphlet No. 2, British Science Guild Publicity Service.**

About 1897 the application by Senatore Marconi of Hertzian electric waves for the purposes of wireless telegraphy began to create public interest. For detecting these waves he first used his improved form of the coherer of Branly and Sir Oliver Lodge. It was, however, rather capricious and somewhat difficult to manage, and Marconi replaced it by his magnetic detector in 1901.

THE THERMIONIC VALVE.

In Marconi's system of wireless telegraphy, the electric waves are generated by creating powerful vibratory currents of electricity in an aerial wire. The electric oscillations in this wire produce in surrounding space an electric wave which travels outwards with the speed of light, viz., 186,000 miles per second. When these waves cut across another similar wire, a receiving aerial, they create in it feeble electric vibrations of the same type.

Now, if means could be found of converting the very rapid alternating movements of electricity in the receiving circuits into a uniform motion of electricity in one direction, it would then be possible to detect them, and therefore the electric waves, by the use of the telephone or galvanometer as in ordinary telegraphy, without the use of a coherer. The vibrations of electricity in wireless telegraph aerials are, however, very rapid, even up to a million per second, and none of the devices for "rectifying" or converting slow alternating electric currents into direct currents are of any use. The Edison effect, however, seemed to offer a solution of this difficulty, and in 1904 the writer found that if a metal cylinder, carried on a wire sealed through the bulb, was placed around the filament inside the vacuous bulb of an electric lamp, the appliance could "rectify" and therefore detect by the aid of a telephone or galvanometer these feeble high frequency oscillations. They cannot directly affect a telephone because of their rapid reversals of directions, but the instrument above described acts as a *valve* when placed in the path of the oscillations and converts them into motions of electricity in one direction, in virtue of the fact that negative electrons are passing in the vacuous space only from the filament to the surrounding metal cylinder.

The apparatus was therefore termed an *oscillation valve,* and afterwards a *thermionic valve.* Later, in 1909, tungsten was used as the material for the filament in place of carbon, as it withstands a higher temperature and emits more electrons. This two-electrode or hot and cold electrode thermionic valve was soon extensively adopted as a means of rectifying and detecting electric oscillations and detecting wireless waves.

In the spark system of wireless telegraphy then exclusively used, the waves come in little groups of 20 or 30 with longer intervals of time between the groups. The Fleming valve rectifies

the groups of oscillations produced in the receiving aerial into short gushes of electricity in one direction, and when these are passed through a telephone they give rise to a more or less musical sound which can be cut up by a key in the transmitter into the *dot* and *dash* or short and long sounds of the Morse code.

Developments of the Fleming Valve.

In 1907 an addition was made to the Fleming oscillation valve by Dr. Lee de Forest, in the United States. After he had become acquainted with the Fleming valve, Dr. de Forest introduced into a low vacuum valve a grid or zig-zag of wire between the filament and the plate. This started a new line of development, and it was found that, if a cylinder of metal gauze or spiral of wire was introduced into the hard or high-vacuum Fleming valve between the cylinder and the filament, it enabled the device to act as an amplifier of oscillations, as well as a detector, so that very feeble high frequency oscillations could be magnified five or ten times by its aid. This suggestion was developed practically by the resources of the Western Electric and General Electric Companies of America.

This modified form, then, became known as a *three-electrode valve*, and is sometimes called for shortness a *triode*, or other trade names. To employ it as an amplifier, a high-tension battery giving, say, 40 to 140 volts, is connected with its negative pole joined to the filament and its positive pole to the plate. A torrent of electrons is then forced from the filament, through the holes in the grid or gauze, to the plate. If, however, a feeble electrification is given to the grid, positive or negative, it increases or decreases this electric current. The grid potential electrification can be obtained from any two points on a circuit in which a feeble high-frequency current flows, and the variation of the plate current of the valve will follow the variations of its grid potential. A number of such valves can be used in series and inter-connected by suitable induction coils or transformers, and the plate current variations in one valve be made to create changes of grid potential in the next valve. By a series of such coupled amplifying valves, feeble electric oscillations can be magnified in any required proportion. It is the invention of this detector, comprising a series of amplifying valves, which has given us a detector of electric oscillations so enormously sensitive that has enabled us to signal half round the world.

The Thermionic Oscillation Generator.

The thermionic valve, in its two- and three-electrode forms, possesses the power not only of rectifying and detecting electric oscillations, but also of creating so-called continuous or undamped oscillations. This discovery at once rendered possible radio-

telephony on a large practical scale, whereas it had previously only been an occasional feat of experts. The proper coupling through a transformer of the grid and plate circuits results in the production in these circuits of self-sustained oscillations by energy drawn from the plate circuit.

During and since the War, improvements have continually been made in the construction of large generating valves. Beginning originally with very small powers of a few watts in valves with bulbs like incandescent lamps, very large valves in glass bulbs, the size and shape of Rugby footballs, yielding an output of 6 or 7 kilowatts, are now made. Valves of 10–20 kilowatts output or more have been made with bulbs of silica. The most recent advance in this direction has come to us from the United States. A method of making high power valves with bulbs partly of glass and partly of copper has been developed by the Western Electric Company of America, based on the fact that a copper tube with a sharp edge can be welded to a glass tube. In large valves a source of trouble is the heating of the metal cylinder by the bombardment of the electrons. In the metal bulb valves the copper part forms also the anode cylinder, and it can be kept cool by immersion in water.

Large generating valves of 10 to 100 kilowatts have been made in this manner, and the General Electric Company of America are said to be preparing a thermionic generating valve of the two-electrode or Fleming type with an output of 1,000 kilowatts or 1,300 horse-power. If this can be done, large thermionic valves will replace high frequency alternators entirely in long distance wireless stations. Already Marconi's Wireless Telegraph Company have a valve panel of 56 large glass valves in their Carnarvon Radio Station with which communication is made direct to Australia. The present public wireless telephone broadcasting stations in Great Britain employ large valve generators in their transmission plant.

Modern Wireless Telephone and Telegraph Valve Receivers.

The improvements made in the construction of the thermionic valve and the close study of its action imposed by the necessity for developing wireless telegraphy and telephony during the War have given us an extraordinarily sensitive and easily managed detector of electric waves, and the advent of wireless telephone broadcasting has created a novel trade in the manufacture of these valves for generating, amplifying and detecting electric waves.

In the receiving valve most commonly used, a straight filament of tungsten, or thoriated tungsten, or else platinum-iridium, coated with oxides of barium and strontium, is used. This is surrounded by a spiral wire forming the grid and by a nickel or

molybdenum cylinder forming the plate. The ends of the filament, grid and plate, are connected to pins on a cap, so that the valve can fit into a socket like an electric lamp.

In modern wireless telegraph receivers, one or more valves are used to amplify the oscillations; one to detect, and one or more to amplify the rectified currents. Valves of this type were made to the number of three or four million during the War (1914–1918) and are manufactured now by the hundred thousand per annum for broadcasting purposes.

The Thermionic Telephone Repeater.

An additional service the thermionic valve renders is as a perfect telephone relay or repeater. Telephone electric speech currents are enfeebled by flowing along a telephone wire, and for long distance working very thick and therefore costly wires were required. Thermionic amplifiers can, however, be inserted in the line to re-enforce the currents.

By the use of these repeaters, telephonic speech is now transmitted right across the Continent of America (4,000 miles), and they are now much used by the British Post Office. For shorter distances a great economy in copper can be obtained by their use. In short, the thermionic valve has effected a revolution in ordinary telephony just as it has made possible wireless telephony.

THE ORIGIN OF SPECTRA.

By Prof. A. FOWLER, F.R.S., Yarrow Research Professor of the Royal Society.

Spectra are of two kinds, band spectra and line spectra. Band spectra are very complex and originate in molecules. Line spectra are of varying degrees of complexity and have their origin in atoms. All compounds which can be excited to luminosity without decomposition give rise to band spectra, but the application of sufficient energy results in the appearance of the spectra of the component elements. Similarly, an element which gives a band spectrum in its molecular form will yield a line spectrum when the energy which excites it to luminosity is capable of dissociating the molecules into their constituent atoms. For example, the band spectrum of oxygen or nitrogen may be produced by the passage through the gas of uncondensed discharges from an induction coil, and the line spectrum by the passage of the more intense condensed discharges.

Some of the earlier workers in spectroscopy were urged on by the idea that a spectrum must provide a clue to the structure of the atoms or molecules which produce it, and probably also to the mechanism of radiation. The majority of spectra, however, are exceedingly complex, and it was evident that the first step towards the elucidation of these problems was to discover the laws governing the distribution of the lines or bands, so that the essential features of a spectrum might be expressed in a simplified form. Theories of the origin of spectra, and of the constitution of atoms, are thus largely based upon investigations of regularities in the arrangement of spectral lines and bands.

In the discussion of such regularities, the position of a line is most usefully indicated by its " wave-number," or number of waves per centimetre. Thus, if λ be the wave-length in vacuo, expressed in Ångström units (1 Ångström unit $= 10^{-8}$ cm.), the wave-number, denoted by ν, is given by $10^8/\lambda$. These wave-numbers are strictly proportional to the oscillation frequencies.

Line Spectrum of Hydrogen.

The simplest of all line spectra is that of hydrogen. In the most familiar part of this spectrum, beginning with a line in the red, the lines follow each other with gradually diminishing intensities and at gradually diminishing distances from each other, so that they approach a definite limit in the near ultra-violet. Lines arranged in this manner constitute a "series" and it was discovered by Balmer in 1885 that the lines of the hydrogen series could be included in the simple formula

$$\lambda = 3646 \cdot 14\ m^2/(m^2 - 4),$$

where m takes successive integer values ranging from 3 to infinity. In terms of wave-numbers, the formula becomes

$$\nu = 27419 \cdot 6 - 109678 \cdot 3/m^2.$$

There is another series of hydrogen lines in the extreme ultra-violet, called the Lyman series from the name of its discoverer, and others in the infra-red, each of which is generally similar in structure to the Balmer series. The entire spectrum is accurately represented by the simple formula—

$$\nu = R\left(\frac{1}{m_1^2} - \frac{1}{m^2}\right)$$

where $m > m_1$ and $R = 109678 \cdot 3$. This number was found by Rydberg to appear in the formulæ for other spectra, and is called the Rydberg constant. In the formula for hydrogen, the Lyman series is given by putting $m_1 = 1$, $m = 2, 3, 4 \ldots$; the Balmer series when $m_1 = 2$, $m = 3, 4, 5 \ldots$; and similarly for the other series in the infra-red.

Series in Line Spectra.

Series which are of generally similar character to those of hydrogen were found by Rydberg, and by Kayser and Runge, to occur in the spectra of other elements. In the general case, several associated and overlapping series occur in the same spectrum, and are distinguished by the names principal, sharp, diffuse, fundamental, and super-fundamental series. Each of such series may be represented approximately by Rydberg's formula—

$$\nu = R\left[\frac{1}{(m_1 + \mu_1)^2} - \frac{1}{(m + \mu)^2}\right]$$

where m_1 and m are integers, and μ_1, μ are constants special to each series. More exact representations of the series are given by including correcting terms in the denominators.

The formula representing a series thus consists of two parts, the first of which indicates the end, or "limit" of the series,

while the second is a variable part dependent upon a sequence of integers. The position of an actual spectral line consequently appears as the difference of two terms, one of which is the limit of the series to which it belongs. The word "term" has thus come to have a special meaning in spectroscopy; it signifies a wave-number which does not represent a spectral line in itself, but only when combined with another wave-number. The limit of a series is a term of one of the other series. The "combination principle" of Ritz expresses the fact that, with certain restrictions, terms from any one series may be combined with terms from other series to produce spectral lines.

Series, and their constituent terms, are now usually represented by abbreviated notations, of which the following are typical:—

Principal series	$1s-mp$
Sharp series	$1p-ms$
Diffuse series	$1p-md$
Fundamental series	$2d-mf$

In each case the term on the left represents the limit of the series, and that on the right the sequence of variable parts corresponding to successive values of m. It should be further observed that series may consist of singlets, doublets, or triplets. In a singlet system all the terms have but one value. In a doublet or triplet system, the s term has a single value, but other terms have two or three values respectively. A triplet system is invariably accompanied by a singlet system.

Elements of Group I in the Periodic Table of Elements, including the alkali metals, give doublet series, those of Group II triplets, and those of Group III doublets. Recent investigations have shown still greater complexities in the terms relating to the later groups of elements, but even and odd multiplicities have been found to alternate throughout all the successive groups. The general increase in complexity of spectrum in passing to the higher groups of elements will be sufficiently indicated by the following abbreviated table:—

I.	II.	III.	IV.	V.
	Singlets.		Singlets.	
Doublets.		Doublets.		Doublets.
	Triplets.		Triplets.	
		Quartets.		Quartets.
			Quintets.	
				Sextets.

In the more complex systems, the s term is always single and the p term always triple, but the complexity increases in the other terms to a maximum indicated by the name of the system. The combination of terms to produce spectral lines is subject to certain selection rules which have been formulated

by the assignment of "azimuthal quantum numbers" to each type of term (1 for s, 2 for p, and so on), and of "inner quantum numbers" to the individual terms. If the combination of terms were unrestricted, spectra would be far more complicated than those actually observed.

The various combinations of terms represented by spectral lines show characteristic resolutions when the source is placed in a strong magnetic field. In a recent remarkable generalisation, Landé has shown how these "Zeeman patterns" may be calculated from the characteristic quantum numbers of the terms involved; or, conversely, how the type of combination may be deduced from the pattern observed.

Origin of Spectra and the Quantum Theory.

In view of the results of the analysis of spectra, it is clear that a successful theory must first account for the terms which give rise to the spectral lines by their combination. The terms have, in fact, a more immediate physical significance than the lines themselves. In the now well-known theory of Bohr, following Rutherford's conception of atomic structure, an atom is supposed to consist of a heavy positively charged nucleus, with a number of electrons circulating round it. In the normal state, the atom is neutral, and the number of external electrons is equal to the number of units of positive charge of the nucleus. When the atom is unexcited, the electrons may be regarded as traversing orbits more or less similar to those of planets or comets travelling around the sun, and obeying similar laws, with the difference that in the case of atoms the controlling forces are electrical.

The nature of the theory may be best indicated by reference to hydrogen, which has the simplest possible structure, each atom consisting of a positive nucleus of unit mass and unit positive charge, and a single electron. When the atom is disturbed, the electron may temporarily traverse a larger orbit, but it is not free to occupy any orbit whatsoever, but only those in which the energy has definite values determined by the Quantum Theory. When the electron traverses one of these orbits, there is no radiation, and the atom is said to be in a "stationary" or non-radiating state. A spectrum line is produced when the electron returns to a smaller permissible orbit. Only one line is produced in a single transition, and the actual spectrum of many lines represents the integrated effect of a large number of transitions between the different permissible stationary states. The energy radiated during a transition is always a single quantum $\epsilon = h\nu$, where h is Planck's quantum of action, and ν is the frequency of the radiation. The frequency of the emission, and therefore the position of the corresponding spectral line, is thus dependent upon the difference

of energies of the initial and final orbits. Exactly what happens during a transition is not yet understood. The "terms" of the spectra which have already been considered are proportional to the energies in the corresponding stationary states.

On this theory, Bohr has obtained a formula for the hydrogen spectrum which is identical with that derived from observations, within the limits of accuracy with which the quantum of action and the charge of the electron have been determined. The theory has also been extended, with remarkable success, to the explanation of the complex structure of the spectral lines, and of the effects of external electrical and magnetic fields.

Atoms of elements other than hydrogen are more complex in structure. A helium atom has a nucleus of mass 4 and positive charge 2 units, and two external electrons. The atom of lithium has three external electrons, and a nucleus with a treble positive charge, and so on throughout the table of the elements, the nuclear charge being equal to the "atomic number" of the element. The spectra, however, do not simply increase in complexity with increase of atomic number, but become more complex from group to group of the periodic table. The structure of the spectrum thus depends on the number of electrons in the outermost group. and not upon the total number. The spectrum is, in fact, considered to be produced by a single one of the external electrons, interacting with the rest of the atom, which, as a whole, will have a single positive charge. Apart from a small effect, due to the mass of the nucleus, the series constant for all elements is, therefore, the same as that for hydrogen. Owing, however, to the presence of one or more electrons in the atomic residue, the possible stationary states are more numerous than in the case of hydrogen, so that several series occur in the same spectrum. The theory, however, is not sufficiently developed to permit the actual calculation of the positions of spectral lines other than those arising from a nucleus and a single external electron.

Arc and Spark Spectra.

Spectra produced in the electric arc and the electric spark, though mostly showing some lines in common, usually exhibit important differences. Lines which are intensified, or only appear, in the spark are called "enhanced lines." Similar differences also occur in the spectra of gases as the energy which excites them to luminosity is increased.

The distinction between arc and spark spectra has become more definite in the light of Bohr's theory. Lines which occur in the arc, excluding those which are stronger in the spark, form series which are characterised by the Rydberg constant R, as already explained, and are attributed to neutral atoms. Enhanced

lines, on the other hand, form series which involve the constant $4R$, and are attributed to ionised atoms; that is, to atoms which have lost an electron. The simplest example is afforded by ionised helium. When a helium atom has lost an electron, it resembles the hydrogen atom, except that the nucleus has a greater mass and has a double positive charge. The spectrum is correspondingly similar to, but not identical with, that of hydrogen; it may be represented by the simple formula

$$\nu = 4R_{He}\left(\frac{1}{m_1^2} - \frac{1}{m^2}\right)$$

where R_{He} is slightly larger than R_H on account of the greater mass of the nucleus as compared with that of the hydrogen atom. This theoretical prediction agrees completely with the actual observations of the spectrum; the important line of ionised helium at $\lambda 4686$, for example, is the first member of the series given by putting $m_1 = 3$.

The spark spectra of elements other than helium show series which differ from those of arc spectra only in having a four-fold value of the series constant; they are also explained in a general way by an extension of the theory similar to that made in the case of arc spectra. It should be noted that in accordance with the so-called "displacement law," the spark spectrum of an element is of the same type as the arc spectrum of the element which precedes it in atomic number.

Spectra of Highly Ionised Atoms.

Bohr's theory further indicates that atoms which have lost two electrons, or are doubly-ionised, may be expected to yield series which are characterised by the series constant $9R$. Trebly-ionised atoms would give series for which the constant would be $16R$, and so on. Series with $9R$ for the constant have, in fact, been established for aluminium by Paschen, whilst both $9R$ and $16R$ series have been traced by Fowler in silicon by the action of strong discharges through silicon fluoride. The chief lines of highly-ionised atoms are of necessity in the extreme ultra-violet, and can only be observed by the use of the vacuum spectrograph. The lines which appear within the ordinary range of observation belong to secondary series, but are, nevertheless, sometimes well developed.

Important contributions to the theory of spectra have also been made by investigations of resonance and ionisation potentials. In these experiments a gas or vapour is bombarded by electrons, the speed of which can be regulated by an adjustable electric field. Energy from an impacting electron is thus transferred to the atom, and is subsequently radiated on the return of the atom

to its normal state. The energy required to develop certain spectral lines, or the complete spectrum, has thus been directly measured and has been found to be in agreement with that deduced from Bohr's theory.

The observational evidence is thus entirely consistent with Bohr's theory, and continued researches on spectra in the directions outlined may be expected to aid in the development of the theory, and in the deduction of the normal structure of the atoms of additional elements.

Band Spectra.

The appearance of a band series is in several respects very different from that of a line series. The constituent lines are usually much more numerous and much closer together; further, although there is a certain resemblance to line series in the crowding together of the lines towards a "limit," series lines invariably fade out before the limit is reached, whilst band lines often reach the limit, and may even have their maximum of intensity in its neighbourhood, so that the resulting "heads" are frequently very conspicuous features of the spectrum. Again, the law according to which the lines are arranged is quite different from that of the lines series, being of the form $\nu = A + Bm + Cm^2$, where A, B and C are constants and m is the number of the line in the series reckoned from any convenient starting point. The arrangement of the heads relative to one another may also be expressed by a formula of this type, which is the analytical representation of a parabola.

Experimental evidence has persistently related band spectra to molecules, but only in recent years has any detailed theoretical explanation been achieved. The quantum principles which have proved so strikingly successful in the elucidation of the problems of atomic radiation are no less applicable to molecules. But the case is considerably more complex, for in addition to the movements of the electrons within the molecule, we have to take into account the vibrations of the atomic nuclei and the rotation of the molecule as a whole. The total energy (W_1) associated with all these motions is characteristic of the particular state of the molecule at the moment, and if a change occurs in one or more of them, the total energy will assume a new value (W_2). Then, exactly as for line spectra, it is found that the frequency emitted (considering the case of a decrease of energy, *i.e.*, of radiation) is given by

$$\nu = \frac{W_1}{h} - \frac{W_2}{h}.$$

It is the greater variety of possible states of a molecule as compared with an atom which gives rise to the greater complexity of a band spectrum as compared with a line spectrum.

The present position is that, while the Quantum Theory has succeeded in accounting for all the main features of band structure, as, for example, the parabolic law mentioned above, there are many details as yet unexplained. Even the simplest bands hitherto studied, those due to helium, present problems of this kind, and in the case of the more massive and complex molecules, many difficulties present themselves. But it seems probable that these very discrepancies will, in the light of further study, provide the material for valuable extensions of our theoretical knowledge.

THE CIRCULATION OF THE ATMOSPHERE.

By SIR NAPIER SHAW, F.R.S.

THE GENERAL CIRCULATION.

Recent progress in our comprehension of the circulation of the atmosphere derives largely from the law of relation between the velocity of air in steady motion and the distribution of pressure in any horizontal surface. If one looks through the meteorological literature of forty years ago, one can scarcely fail to be impressed with the notion that the writers always had in mind the conditions of starting and stopping, and thought little about the long stretches of the travel of the air. These stretches represent neither starting nor stopping, but steady or persistent motion under balanced forces, provided that we are permitted to include among the forces the effect of the rotation of the earth, which can be neither avoided nor ignored in any general atmospheric question. Yet it is no exaggeration to say that, with the motion of the atmosphere, starting and stopping are of no greater importance than they are in the passages of ocean-going steamers or non-stop trains.

We know that at the surface of the earth, from which most of our experience of weather is derived, there never is and never can be the steady motion which represents the balance between the gradient of pressure and the rotation of the earth, because the friction between the moving air and the earth or sea is always dissipating the energy of motion in eddies and ultimately in heat. To compensate for that loss and keep the motion steady, some force driving the air along its path would be required, but it is not forthcoming. However, in the free air above the surface at the height of a kilometre or two, say, 5,000 ft., we need not think any longer about the disturbances due to the surface, and there, provided we are not directly involved in the convolutions of a cyclone, we may rely upon what is called " the geostrophic wind,"

that is to say, a wind along the lines of equal pressure (*isobars*), with velocity inversely proportional to the distance between consecutive isobaric lines, as a valid normal representation of the actual wind.

The consequence of this recognition of a simple dynamical relation between undisturbed wind and pressure-distribution is that a " geostrophic scale " always lies on the modern meteorologist's working chart, and when he wants to know the effective wind, disregarding the surface-friction, he lays his geostrophic scale across his isobars and reads off the result in metres per second or miles per hour as he pleases, or as it pleased the person who made the scale.

Use of Pilot Balloons.

The general introduction of the use of pilot-balloons for determining the motion of the free air brings at one and the same time confirmation of the general principle and challenge of the individual facts. The assumption of the relation brings the winds of the upper air within the possibility of mathematical calculation in a manner which surprises all who take up the questions treated.

From this position, which is a very natural extension of Buys Ballot's law, it follows immediately that, if by any means we can determine the distribution of pressure at any level in the atmosphere, we can determine the horizontal velocity of the wind at that level by the simple process of laying a properly graduated scale across the isobars which represent the distribution of pressure.

Pressure-Distribution in the Upper Air.

The barometric equation of Laplace gives us the means of calculating the pressure to be deducted from the value at the surface for any step of height when we know the temperature of the air at each level. Such a determination of pressure in the upper levels, without observations carried out on the spot *ad hoc*, may be regarded as being beyond the discretion of a cautious meteorologist when he is dealing with the distribution of pressure of to-day or yesterday, as represented on a " synchronous " chart of actual pressure and temperature at a definite epoch, with all the peculiarities of the meteorological situation and its local incidents; but it is not at all out of the question when we come to deal with average conditions representing the mean result of observations for an individual month extending over so long a series of years that the transient local conditions are merged in the general picture.

The reason for supposing that we can calculate the distribution of pressure at an upper level from the observed pressures at the surface, with sufficient accuracy for general purposes, is derived

from an entirely unexpected result obtained from records of registering instruments sent up on balloons, known as "sounding balloons." They carry instruments but no passengers. Things are so arranged that after an upward journey of from 6 to 10 miles or even more, a balloon bursts and comes down with the instrument. The instrument and its precious record reach the earth undamaged within about two hours of the start and within a hundred miles or so of the starting point.

Records obtained in this way, in Europe to begin with, and then in America, over the Atlantic Ocean, the Greenland seas, the Antarctic, the Victoria Nyanza, the Dutch East Indies and Australia, disclose the remarkable fact that, provided the temperature at the surface is the highest of the record, the rate of fall of temperature with height is the same in any part of the world. There are a good many occasions, particularly in the winter of the locality where the sounding is made, when the surface is colder than the air in the layers immediately above it, and then there is no satisfactory starting point for calculating pressure in the upper air. Even on these occasions the régime of the fall of temperature with height according to the numerical rule asserts itself when a certain height has been attained; but that does not help us in the calculation of pressures in the upper levels because the starting point at the surface is off the line by an altogether unknown amount.

Confining ourselves to summer-temperatures, therefore, in which that difficulty does not arise, the pressures in the upper levels have been calculated with some assurance that we are at least within the range of probability, and on this basis the distribution of pressure over the northern hemisphere in July has been calculated for 2 km., 4 km., 6 km., 8 km., and 10 km. The results are represented upon maps or models for the corresponding levels.

Normal Atmospheric Calculation.

The distribution of pressure being known, we can calculate the normal atmospheric circulation at the surface and at the different levels. It is very complicated at the surface, but becomes much simplified at 2 km. At higher levels the régime is clear; it is a circulation from west to east round the pole, not quite along circles of latitude because there is some distortion of shape consequent upon the transitions from land-areas to sea-areas and *vice versa.* The circumpolar circulation, west to east, extends to about latitude 30°; there it falls off very rapidly, and along the equator and intertropical belt, there is a circulation in the opposite sense, from east to west.

The two circulations at any level are not altogether independent: there are limited regions, along the latitude 30°, around

which apparently air may pass from the equatorial circulation to the polar circulation and *vice versa*. These localities seem to supply moving belts which carry, or gear with, the east to west circulation on the southern side and the west to east circulation on the northern side.

The final conclusion has been reached by Mr. A. W. Lee that, so far as the polar circulation is concerned, and apart from the local disturbances due to coast-lines, the successive layers of our atmosphere are rotating " like a solid." The west to east velocity represents a travel a little faster than that of the solid earth, the values of the angular velocities of the successive shells in July being $1{\cdot}03\omega$ at 4 km. and 6 km. and $1{\cdot}05\omega$ at 8 km., where ω is the angular velocity of rotation of the earth. The corresponding velocity for January, as determined from a chart of isobars by Teisserenc de Bort, is $1{\cdot}08\omega$. The intertropical circulation at high levels has an angular velocity of $0{\cdot}92\omega$, which represents a motion relative to the earth from east to west of $0{\cdot}08\omega$, but at lower levels the relative motion westward is much less. These figures mean that a shell, from 4 km. to 6 km. high, makes a complete rotation with regard to the earth from west to east in 33 days in summer and 12 days in winter. Another higher shell at 8 km. takes only 20 days to complete a spin even in the summer. On the other hand, the higher air over the equator gets round the earth the opposite way in 12 days.

Local Disturbances in the Circulation.

This simple régime, so easily imagined and remembered, does not, however, reach the surface. There we find a complication which only a carefully constructed map can represent. If we seek for an explanation of that complication we must remember that, whereas during the day, when the surface is solarised, the layer of earth and sea is receiving heat from the sun, the opposite is the case at night, and long before night in the regions of long shadows. There the surface is losing heat, and as an inevitable consequence air runs down the shaded hills more and more as the shadows lengthen and deepen. How much air runs down and how fast it runs we do not know, but we know that the flow must be there and huge pools of cold air must accumulate in the lower levels. Moreover, the process is irreversible; cooled air must stick to the ground, warmed air cannot. Hence we may regard the shadowed hills as pouring an immense volume of air on the lower regions, and thereby spoiling the simplicity of the distribution of pressure at the surface, and consequently that of the general circulation of the atmosphere in the lower layers.

There can scarcely be any question that the descent of cold air in this fashion expresses itself in the play of the general circulation as local modifications of the distribution of pressure at the

surface and the formation of seasonal anticyclones. The converse process, the ascent of warm air, is another story and a much more complicated one. The descending air, which of necessity clings to the hill-side, can always take advantage of the cooling of the ground, and is thereby helped all the way; it goes down headlong like an avalanche; but to climb, air has to leave the ground and make its way through the layers above with only the trifling assistance which it can obtain from the absorption of radiation by the water vapour which it carries. While rising it is subject to the automatic reduction of its temperature consequent upon the reduction of its pressure, if no heat is supplied to it. It loses heat at the rate of 1°C. for 100 metres, while the temperature of the environment falls off with height generally only 1°C. for 200 metres. The transparent air through which we see the sun and stars looks perfectly similar and homogeneous, and is all called simply air; but it is really stratified by its temperature into layers which are quite impervious to air rising from below, unless the rising air has the temperature necessary to furnish the key to get through.

> Facilis descensus Averni,
> Noctes atque dies patet atra janua Ditis;
> Sed revocare gradum superasque evadere ad auras;
> Hoc opus hic labor est.

Yet the air as we know it manages the ascent quite easily by an ingenious trick. It climbs to higher things on stepping-stones of its own dead water vapour. It loads itself with moisture. As it rises it cools, and, if it is fortunate enough to pass the dew point, it condenses part of its moisture and takes over the heat of vaporisation previously latent, but now set free. Fortified therewith, it passes on its victorious way upwards, sometimes with a rush great enough to carry up huge hailstones, until it meets its match in an environment that has less lapse of temperature with height than the rising air itself, in spite of its propensity to appropriate the latent heat of its accompanying water.

At and above a height varying with latitude from some 8 kilometres at a pole to 17 kilometres at the equator, there is a layer of air called the "stratosphere," where there is no fall of temperature with height. That layer even the wettest atmosphere can never penetrate; it cannot be overcome either by *opus* or by *labor*—it is just impossible and impassable.

However, in the "troposphere," the region that lies between the ground and the stratosphere, all kinds of enterprises are possible to rising air fortified with a sufficient supply of water vapour: Clouds, rain, hail, snow, thunder, lightning and nearly all the other incidents of weather.

These striking phenomena are most notable characteristics of the local disturbances of the general circulation which are called cyclones or cyclonic depressions. This has been recognised for a

long time, and many meteorologists have thought that the cyclones really derive their energy from the convection of wet, warm air. Certain it is that if a rapid vertical ascent of air took place within the normal circulation, the circulation would be disturbed; the only question is by how much. It is also certain that if the layers of air in the middle atmosphere were traversed by air coming from below and passing out above, the rising air would carry with it from the middle layers more than its own mass, and the result of the eviction would necessarily be such a circulation as we may associate with a cyclone freed from the friction of the surface. But, as yet, we cannot speak with certainty as to the extent to which the origin or maintenance of the energy of a cyclone is due to the travel of air upward through the layers with the aid of the condensation of water vapour. By means of diagrams which represent the thermodynamic changes in dry and saturated air under continuous reduction of pressure, and also the conditions of the environment, we are now able to estimate numerically the amount of energy which is available for these dynamical operations.

The new school of meteorologists in Norway traces the origin of cyclones to the mutual action of two currents of air across a surface of discontinuity and regards the accompanying weather as incidents of no dynamical importance; a vortex as only the transient final form of wave-motion. On the other hand, a Japanese student of the Imperial College has recently shown that a vortex with its recognised distribution of pressure, travelling along at the height of a kilometre, would produce automatically in the layers near the surface the phenomena upon which the Norwegian school bases its conclusions.

The Complexity of the Kinematic Structure of the Atmosphere.

The measurements of the direction and velocity of the air at different levels obtained by the observation of pilot balloons afford information of the kinematic structure of the atmosphere in clear weather. The information can be supplemented by observations of the motion of clouds of various forms and sometimes by observation of pressure and temperature in aeroplanes.

To gain a general idea of the kinematic structure, the results of soundings with pilot balloons have been combined in various ways. One of the most instructive methods is to set out the direction and velocity at different levels on glass plates, using one glass surface for each level. The plates are put together to form a block, in which the motion at the various levels is easily apparent.

Models of this kind, in which the results for different stations are combined with a map of the distribution of pressure at the

surface of the same time, show very clearly the complexity of the dynamical problem of the motion of the atmosphere at any moment. They remind us that the actual motion depends partly on the conditions of general and local circumstances, represented by the distribution of pressure, and partly on minor local disturbances not otherwise represented, which for the moment must be regarded as accidental disturbances of dynamical or, perhaps, of thermodynamical origin. Hypothetical combinations can be represented in like manner.

Something is already known about the dynamical effects of the inequalities of land-surface, but scarcely anything about the thermodynamical effects, and it would be well if these could be reduced to the simplest form. Hence the most inviting line of approach to a solution of the kinematic problem is by way of observation of pilot balloons at sea, where the surface conditions are free from many of the complexities of land-areas.

The Analysis of Atmospheric Motion.

The general meteorological problem would be brought within more manageable limits if we were able to analyse the complex motion of the air into combinations of motion of recognised types even for a few occasions. Certain combinations, not very well defined, however, are familiar in meteorological literature, such as translation and vortical rotation, secondary vortical rotation within a larger vortical rotation and wave motion combined with translation, but none of these ideal structures can be recognised in ordinary weather maps, nor are they likely ever to be recognised *prima facie* in a surface map, because the friction of the surface air affects the motion in every combination.

In meteorological practice certain features are selected as suggesting certain ideal combinations the consequences of which are traced as a basis of forecasting. Finality cannot be reached until the existence of these ideal combinations can be demonstrated by reference to the actual atmospheric structure. On a few occasions, with suitable correction of the surface observations, the analysis can be exhibited, and meanwhile, to afford a clue to possible analysis, the study of ideal combinations on the scale of the weather map may be pursued by the construction of synthetic weather-charts.

Systematic Units of Measurement.

It is acknowledged by all, however, that the phenomena of the atmosphere represent the working of an exceedingly complex air-engine or steam-engine, and that the ultimate explanation of the local disturbances, as of the normal circulation, must be looked for in the quantitative relationships of all the physical quantities

inherent in the atmosphere. Gravity, heat, work, temperature wind-velocity, solar radiation, terrestrial radiation, vapour-pressure, all are associated and all will have to be combined when the explanation comes to be worked out. If that be accepted, it is just as important for meteorologists to provide themselves with units of measurement on a systematic plan as it was for electrical workers fifty years ago. When we have to combine temperature with pressure in a formula, the measurement of temperature as a number of degrees from the freezing point of water has to be changed, whether the operator is aware of the fact or not. When we have to deal with the intricate relations of heat and work in the atmosphere, to have to introduce a factor A or J, the very definition of which is uncertain, is adding to the inevitable *opus* and *labor*.

Hence one of the first steps in the explanation of the circulation of the atmosphere, when it comes to be written, will be the setting out of the measurements involved in systematic units; and therefore, as it will certainly be indispensable in the end when the work is done, so it will make things easier as the work proceeds. Thus we build our representation of the present state of knowledge of the circulation of the atmosphere, and the means of extending it, upon the foundation of meteorological quantities expressed in systematic units.

THE WATER IN THE ATMOSPHERE.*

By Dr. G. C. SIMPSON, F.R.S., Director of the Meteorological Office.

The dictionary definition of "saturation" is "the state of a body when quite filled with another," and it is usual to think of saturated air as air which is full of water vapour to such an extent that further water cannot be added without condensation taking place. This, however, is a wrong conception, for there is no limit to the amount of water vapour which air can contain at any temperature, provided that it is perfectly pure, except that ultimately the molecules of vapour will be so near together that there will be no distinction between vapour and liquid.

We will describe air as saturated when the water vapour it contains is in equilibrium with a flat surface of pure water at the same temperature. This will define the saturation pressure at each temperature, and relative humidities will be given as percentages of this saturation pressure.

It is well known that water can be cooled below its freezing point without becoming ice, and therefore water and ice may exist side by side over a large range of temperature. But the vapour pressure which is in equilibrium with ice at a given temperature is lower than that which is in equilibrium with super-cooled water at the same temperature ; that is, air is in equilibrium with ice at a relative humidity below 100 per cent. Thus, according to our definition of relative humidity, the water vapour in air may be in equilibrium with water over a large range of relative humidities according to the physical state of the water present.

CONDITIONS FOR CONDENSATION.

It was in 1880 that Aitken first showed that condensation does not necessarily take place in air when its temperature is lowered

* Abstracted from Supplement to *Nature* of April 14, 1923.

below that at which the water vapour it contains is sufficient to saturate it (dew point). He expanded carefully filtered air and found that no fog formed even when there was considerable supersaturation. Aitken concluded "that vapour molecules in the atmosphere do not combine with each other, that before condensation can take place there must be some solid or liquid nucleus on which the vapour molecules can combine, and that the dust in the atmosphere forms the nuclei on which the water vapour molecules condense."

Aitken invented a most ingenious instrument, easy to work and very transportable, by means of which it is possible to count the number of nuclei present in the air. Tests made with this instrument show that nowhere is air free from nuclei. Their number is seldom less than 100 per c.c., while in most country places the nuclei rise to thousands, and in cities such as London and Paris the number may be so great as 100,000 to 150,000 per c.c.

The general explanation of these observations is as follows. If there were no dust particles present the drops of water would have to be built up from aggregates of water molecules; if a few molecules met together by chance, they would form so small a drop that it could not exist unless there was large supersaturation. If, however, there were dust particles present, the molecules of water would be deposited on them, and the radii of the initial drops would be so large that little supersaturation would be required to maintain them.

This explanation appeared to satisfy everyone for a long time. In 1912, however, Wigand found that even when he created large clouds of dust he could not find any increase in the number of nuclei in his condensation apparatus. Apparently Aitken's instrument does not measure the number of dust particles present, but the number of hygroscopic particles, and meteorologists are now of opinion that condensation commences on these hygroscopic substances.

Köhler, working in Norway, is tempted to contend that sea-salt provides these particles. It is, however, not necessary to go so far as this, for there are many other sources of hygroscopic substances. Lenard and Ramsauer have shown that sunlight—probably only the ultra-violet part—acts on the oxygen, nitrogen and water vapour of the atmosphere, producing very hygroscopic substances.

Large quantities of material capable of becoming condensation nuclei, however, are produced by all processes of combustion. Thus the household fires and factory chimneys of centres of industry produce vast quantities of nucleus-forming material, chief of which is sulphurous oxide. This, when illuminated by sunlight in the atmosphere, is a very hygroscopic substance capable of causing condensation in unsaturated air. It is estimated that in England something like 5,000 tons of sulphur are burnt each day in coal fires, giving enough sulphur products to pollute the atmosphere

from Land's End to John o' Groats. Other products of combustion are also hygroscopic; thus it is not surprising that air from large industrial centres contains enormous quantities of nuclei.

When the temperature of the air is below the freezing point, it is inconceivable, owing to the small amount of vapour present, that condensation will take place by the fortuitous meeting of molecules; some kind of nuclei therefore will be necessary.

When sledging in the Antarctic with Captain Scott in 1911 we became enveloped in a fog during sunshine. On the fog opposite the sun we saw a white bow in the position usually occupied by a rainbow. This phenomenon can only be explained on the assumption that the fog was composed of small spheres. But the temperature was $-29°C.$ $(-21°F.)$ and almost a dead calm existed at the time; hence these drops could not have formed at a high temperature and then been super-cooled. The only explanation appears to be that in the clear air of the Antarctic, where there are no "dust" particles suitable for condensation available, there are plenty of hygroscopic molecules of some sort.

Haze.

Perfectly pure air is almost completely transparent to visual light waves, and if the air were always pure we should see distant objects through air almost as clearly as through a vacuum. But there are always more or less particles of foreign matter present. The action of these particles is two-fold: first, they reduce the amount of light reaching the eye from distant objects; and, secondly, in the daytime they scatter the general light of the sky and so send to the eye extraneous light which reduces the contrast between distant light and dark objects on which visibility depends. Generally this foreign matter consists of a mixture of solid ponderable particles and hygroscopic molecules. In perfectly dry air the latter would be practically invisible, but when loaded with water in a humid atmosphere they add to the obscurity of the atmosphere.

Haze is due to this kind of obscurity, and varies in intensity from the slight obscurity of polar regions, which depends almost entirely on the hygroscopic particles, to the dense obscurity of a dust storm in tropical regions, which is due almost entirely to solid particles.

Mist.

If the temperature falls below the dew point, the hygroscopic particles are sufficiently large to form excellent nuclei for condensation, and relatively large amounts of water are deposited for small falls of temperature. Real condensation has now commenced, and the obscurity changes from that of haze to that of mist. The whole process of the formation of haze and mist is continuous, but they are fundamentally different, for haze owes its origin to foreign

matter and the small amount of water associated with hygroscopic nuclei, while mist is due to an actual precipitation of water from vapour to liquid.

Fog.

There is no fundamental difference between mist and fog : in most cases fog is only a dense mist, and the density at which mist becomes fog is a matter of definition. It is now the practice of the London Meteorological Office to limit fog to the obscurity in which objects at 1 kilometre are not visible.

When mist and fog are formed in fairly clear air they are white. On the other hand, if the air contains a large quantity of impurities, such as carbon particles from imperfect combustion, the mist particles absorb the impurities and become themselves dark-coloured. In this way are formed those dense fogs in London which are likened to pea soup. It was originally thought that the density of a London fog was due to the fact that the smoke of the city provided an unusually large number of nuclei on which condensation could take place, thus offering a temptation to the air to deposit its moisture which it could not resist. As a matter of fact, there are always sufficient nuclei in the purest air in England to allow of the formation of fog whenever the meteorological conditions are suitable.

The relationship between smoke and fog is peculiar, and may be said to be accidental. The meteorological conditions which are necessary for the formation of fog are such that, while they last, smoke cannot get away either vertically or horizontally from the place of its origin. Thus during a fog practically all the smoke which London makes is kept over it and within a few hundred feet of the ground. This smoke, combined with the deposited water, can, as we all know, produce such an obscurity that midday is as dark as midnight. The total abolition of smoke from London would not reduce the occasions on which mist and fog occur, but many fogs would remain mists, and we should never have a "London particular." The fogs of London are caused almost entirely by loss of heat from the lower layers of the atmosphere into a clear sky above. The air radiates its heat, its temperature falls, and condensation takes place. Other methods of fog formation, such as the mixing of warm and cold air, are of secondary importance and never give rise to more than patchy local mists or light fogs.

Clouds.

When air not saturated rises in the atmosphere its temperature is reduced by about 1°C. for every 100 metres of ascent. When the ascent is carried far enough the dew point is reached, after which any further rise will cause condensation on the nuclei present. As the ascent is carried beyond the point of condensation, more and more water is deposited, with a consequent increase in the size of

the drops. This is the manner in which clouds are formed, and there are very good reasons for saying that it is the only way. Thus there is a fundamental difference between the method of formation of clouds and fogs : fogs form without any ascent of the air, while clouds are never formed without it. Thus it is not correct to describe clouds as fogs of the upper atmosphere.

The very sharp line of demarcation between the air under a cloud and the cloud itself needs explanation. The hygroscopic nuclei collect more and more water around them as they rise with the ascending current, owing to the increase in relative humidity. But when saturation is reached they are still very small, and produce little obscurity in the air. Such drops, however, need only 1 per cent. supersaturation to grow. Moreover, they are unstable, for as they grow they need less supersaturation. Thus, as soon as the air is sufficiently supersaturated to be in equilibrium with the nuclei, the slightest further rise causes the drops to grow very rapidly to the size in which they are in equilibrium with saturated air. The height at which this change occurs is the height of the base of the cloud.

Rain.

When bodies fall through a resisting medium, such as air, they more or less quickly reach such a velocity that the resistance of the air equals the pull of gravity, after which they fall with a constant velocity, which is different according to the density and shape of the falling bodies.

Experiments have been made to determine the rate of fall of water drops through air at atmospheric pressure, and they show that the small drops in clouds would fall only at the rate of a little over a centimetre a second. As the drops get larger the rate of fall tends to a constant value of about 8 metres a second, while drops half a centimetre in diameter have the most rapid fall. Larger drops fall more slowly, for, instead of retaining the shape of spheres, they become flattened out, thus presenting an increased resistance to the air through which they are falling. When the size of the drop is such that, if it were not flattened it would have a diameter of about half a centimetre, the drop becomes very unstable, and all drops larger than this quickly break up into a number of smaller drops, which of course fall more slowly. This means that raindrops can never fall through air at a greater velocity than 8 metres a second. Small drops fall slower than this, and large drops flatten out as soon as they are falling at 8 metres a second, and then soon break up into smaller drops.

W. H. Dines has found that in Europe the quantity of vapour in air is always very small. If the whole water vapour in the atmosphere on an average summer day were precipitated, it would only give a total rainfall of 0·80 in. The greatest amount ever measured on a summer day in Europe would only give 1·5 in. of rain, and, of course, the quantity is much less in winter. Rainfall

of several inches of rain in the course of an hour or so such as occurs in the tropics is due to ascending currents which carry with them their own water vapour to supply the rainfall. Ascending currents up to many metres a second are possible, and do occur in the atmosphere. Let us think of air rising at about 10 cm. per second, which is the order of the upward velocity of the air in depressions. At a certain height cloud particles form as already described. These have a radius of about 0·001 cm. and fall relatively to the air at 1·3 cm. per sec.; hence they are carried upwards with the air, but the base of the cloud remains at the same height because new cloud particles are constantly being formed at that height. As the air rises the cloud particles grow in size, because water is being condensed on them, and they lag more and more behind the air. Drops with a radius of 0·002 cm. are falling as rapidly as the air is rising, and therefore remain stationary, while drops of 0·007 cm. are falling at the rate of 1 metre a second, and therefore fall through the rising air and appear at the earth's surface as rain. This process will continue so long as the ascending currents continue, and in this way we get the continuous steady rain with which we are so familiar in this country.

When the upward velocity of the ascending air becomes greater than 8 metres a second, no water can fall through the ascending air for the reason already explained. All water condensed in such an upward current—and it will be a very large amount—is carried upwards until the upward air velocity falls below 8 metres a second, as it is bound to do at some height owing to lateral spreading out. Here water accumulates in large amounts. It is the sudden cessation of the upward velocity in such an ascending current which gives rise to the so-called cloud-bursts, for when the sustaining current stops, the accumulated water falls just as though the cloud had literally burst.

The accumulated water while it is suspended in the air is constantly going through the process of coalescing into large drops, which at once become deformed and broken up again into small drops. Every time a drop breaks there is a separation of electricity and this is probably the chief source of electricity in a thunderstorm. This explains why thunderstorms are associated with heavy rainfall and do not occur in polar regions, where there is no rain.

HAIL.

Let us consider a region in the atmosphere through which there is an ascending current of air. The air is supposed to have a temperature of 20°C., and a relative humidity of about 50 per cent. at the ground. As the air rises, at first its temperature is reduced by 1°C. for each 100 metres of ascent. Hence, by the time it has risen 1,000 metres its temperature will have been reduced to 10°C., and it will have reached its dew point. Here the cloud

level begins. As it rises still farther its temperature continues to decrease, but not so rapidly as before, because the condensation of water vapour releases the latent heat of vaporisation. It reaches 0°C. at a height of 3,000 metres. Hence the region between 1,000 and 3,000 metres contains only drops of water. As the air rises above 3,000 metres the temperature falls still lower, but the water particles do not freeze at once, they remain super-cooled. We may assume that at -20°C., which is reached at about 6,000 metres, the super-cooled drops solidify and the remaining part of the cloud above this level is composed of snow alone.

There will not be a sharp division between the region of super-cooled water and the region of snow. For a certain distance ice crystals and super-cooled water will be mixed together. Such conditions are very unstable, the ice particles grow rapidly, and, if the ascending current is not too large, they will commence to fall. The ice-particle has, however, to fall through 3,000 metres of super-cooled water drops, and in doing so it grows appreciably. As each super-cooled water particle strikes the ice it solidifies, and also imprisons a certain amount of air, so that by the time the ice particle reaches the bottom of the super-cooled region, it is simply a ball of soft white ice.

If the descent through the super-cooled region has been fairly rapid, the temperature of the ice ball will be considerably below the freezing point when it arrives in the region where the temperature is 0°C. and the cloud particles are not super-cooled. As it continues its way downwards it receives a considerable addition of water : in the first place by direct deposition, because it is colder than the air ; and, secondly, by collision with the water particles. This water covers the surface of the cold ice ball with a uniform layer of liquid which quickly freezes into clear solid ice, with little or no imprisoned air. Finally, the ice escapes from the bottom of the cloud, and falls to the ground as a hailstone.

When hailstones are split open to show their internal structure we can nearly always see the inner soft white mass of ice which was collected while the stones were in the super-cooled region, surrounded by a layer of clear transparent ice formed by the freezing of the water deposited when the stone was passing through the non-super-cooled region.

Hailstones are formed only during thunderstorms, when violent ascending currents of air occur. Thus, while the hailstone is growing in size, its rate of fall may well be less than the upward velocity of the air. All the time, however, it will be moving relatively to the air, and its effective height of fall will be great. This would enable it to collect water, and so would account for the large size often attained by hailstones. Moreover, such an ascending current is not steady. Just as there are gusts and lulls in horizontal winds, so there are increases and decreases in the velocity of ascending currents. Thus a hailstone which has

penetrated into the lower part of the cloud might be blown upwards and so go through the whole process again. In this case we should have a layer of white ice deposited around the clear layer, around which again there would be another layer of clear ice. This process might be repeated indefinitely, giving several concentric layers of clear and white ice, and a broken stone would have the appearance of an onion. Such cases are not at all uncommon.

For the formation of hailstones two conditions must be fulfilled :

(*a*) The clouds must extend through a great vertical height so that the three regions of water particles, super-cooled particles, and snow are extensive and well developed.

(*b*) There must be violent ascending currents, otherwise the stones would fall too rapidly to grow to a large size.

These conditions are best fulfilled in warm regions, for there violent ascending currents are most easily developed, and the condensation starts at a relatively high temperature, so giving regions of water particles and super-cooled water particles of great depth. These are the reasons why hailstones only occur during the summer in temperate regions, and why the most violent hailstorms and the largest hailstones are found in tropical regions.

Soft Hail.

The hailstone receives its coat of clear transparent ice in the region between the bottom of the cloud layer and the zero isothermal. If this region is much reduced, as when the temperature at the ground is low, the hailstones are relatively small, and consist only of the soft white balls appearing in the centre of the more complete hailstones. Falls of soft hail of this nature are quite common in the winter in Europe. The temperature of the ascending current is so low that the freezing point is reached almost at the bottom of the cloud, so the hail falls almost immediately out of the region of super-cooled water particles, and has no opportunity for building up a layer of transparent ice.

Snow.

Snow which forms over an ascending air current in which water particles first form will probably have solidified cloud particles for nuclei. Whatever the nuclei may be, as soon as the initial crystals are formed, further condensation takes place exactly as in the precipitation of water, but the vapour condenses directly into the solid state without first going through the liquid state. The crystals of water are hexagonal prisms. Having once started, the crystals may grow either along their central axis, giving rise to long thin prisms, or along their six axes to form hexagonal plates,

showing all the wonderful shapes that this form of crystallisation can take.

In cold regions the crystals are small, because there is little water vapour present from which they can grow. In the Antarctic during the winter, when the temperature was always near or below 0°F., only the smallest crystals were seen, so small that they were almost like dust.

When crystals form at temperatures near the freezing point they grow to their largest size. When the air is full of large crystals frequent collisions take place. The crystals become interlocked and bundles of many separate crystals are formed; these produce the ordinary snowflakes which, on account of their size and weight, fall relatively rapidly. It is to these latter that the term snow should be applied.

RADIATION AND THE ATMOSPHERE.

By F. J. W. WHIPPLE.

In a general way, we all realize that the earth is only habitable because of the heat received by radiation from the sun. How that heat is distributed and ultimately lost is one of the fundamental problems of meteorology.

For our knowledge of the quantity and quality of the energy in the sun's rays on the confines of the earth's atmosphere, we are indebted to Langley, Abbot and Fowle, workers attached to the Smithsonian Institution of Washington. By means of the spectrobolometer, an instrument in which the principles of the spectroscope and the thermopile are combined, Abbot and Fowle determine the energy in each part of the spectrum of the sunshine that reaches their observatory. This being done several times in the course of the day, both when the sun is low so that the heat flow is considerably obstructed by the atmosphere, and when the sun is high so that the obstruction is as little as possible, the observers are in a position to estimate the energy in the unobstructed radiation.

In the first instance it was tacitly assumed that the strength of the solar heat stream would not vary, and the term " solar constant " came into use to denote the rate of flow of thermal energy outside the atmosphere, but at the average distance of the earth from the sun. There is, however, strong if not conclusive evidence that the " solar constant " varies from day to day, the sun being in fact a variable star. The average value of the " solar constant " is such that, in the course of 24 hours, the earth receives enough heat to raise the temperature of a layer of water a metre deep by 7°C., to melt a layer of ice 9 cm. deep, or to evaporate a layer of water 12 mm. deep.

It is instructive to notice that a body like a meteor, with no atmosphere, but so small that its temperature was equalised by conduction, would have a temperature of about 10°C. At such

a temperature the outward radiation would just balance the radiation received from the sun. In the case of the earth, conduction is ineffective, but the movements of the atmosphere and the oceans tend to equalise temperature, and the average temperature of the air near the ground does not differ greatly from that of the hypothetical meteor.

The observations from which the value of the "solar constant" is deduced show, also, how much of the radiant energy is absorbed in the atmosphere or dispersed by it. When the air is free from haze (solid particles), and also from mist or cloud (water in the liquid or solid state), there is little absorption, but much of the incoming light is dispersed by diffraction. The light of shortest wave-length is most liable to diffraction; the diffracted light gives us the blue sky and the blue of the distant landscape seen through air illuminated by sunshine. The longer waves are not diffracted so much; the setting sun seen through a great thickness of clear air is yellow or orange, and only the red rays survive in light which passes from a low sun to the clouds and then to earth.

The scattered radiation also plays its part in warming the earth, though half of it passes away into space and is lost.

In contrast with the transparency of the atmosphere to the short-wave radiation which we call light is its absorption of the long heat waves. The stopping power is mainly due to the presence of water vapour in the atmosphere, though the carbon dioxide helps. Water vapour acts like the glass firescreen, which lets us see the fire but cuts off the heat. Thus the heat which the earth's surface loses by radiation is absorbed by the air. Some of the heat comes back to earth as radiation, some is sent on its way into outer space.

Here we have the explanation of some very remarkable facts. It is well known that it is colder at such heights as have been reached by mountaineers and airmen than on the ground, but no speculator had suggested that the cooling with increase of height would stop short at a certain level until that was revealed by the instruments sent up on small free balloons. In our latitude, the limiting temperature is reached at a height of about six miles; over the equator the limit is found at about nine miles: near the poles at four. The temperatures recorded 10 miles up over the equator, averaging −80°C., are the lowest that have been found under natural conditions in the atmosphere. Over the poles the average is higher, about −45°C.

Exactly why this happens has not been determined, but the point of greatest importance is, no doubt, the excess of water vapour in the tropical air. The air of the polar regions holds very little water vapour—perhaps enough to make half an inch of rain. Near the equator there may be six times as much. If the polar regions be thought of as a glass-house with one thickness of glass, the tropics have six thicknesses. In spite of the higher temperature inside the well-protected house, less heat escapes from

it to the outermost glass surface. In spite of the higher temperature at sea level in the tropics, less heat escapes to outer space than from the polar regions. The superfluous heat from the tropics is conveyed by the winds, mostly by the upper winds, to the parts of the globe where escape by radiation is possible.

Thus the curious distribution of temperature in the atmosphere, coldest on the ground near the poles, coldest at considerable heights over the equator, is mainly due to the way in which radiation is affected by the presence of water vapour.

ATMOSPHERIC ELECTRICITY.

By Dr. C. Chree, F.R.S.

According to current ideas, the earth carries a negative charge of electricity of some 700,000 coulombs, while the loss of charge represents a current of some 1,000 amperes. Thus the capital represents only some 12 minutes' expenditure, and yet bankruptcy does not ensue. It is thus clear that the relations between the loss and the accumulated charge must be widely different from what is supposed, or some unknown active source of replenishment must exist.

On investigation it will be found that our information is very incomplete, both as regards the charge and the air-earth current which represents the loss. Our information as to the latter is particularly meagre. There is, however, a consensus among observers that an air-earth current is constantly flowing, and that in fine weather it almost invariably represents a transfer of positive electricity downwards (or negative electricity upwards). The most exact measurements of its intensity are probably those made by Prof. C. T. R. Wilson, whose mean value, 2×10^{-16} amp. per cm.^{2}, has been used in the estimate given above.

The charge σ per cm.^{2} is not measured directly, but is calculated from the observed value of the potential gradient— *i.e.*, the surface value of the vertical electric force. In fine weather the potential normally rises as we ascend. In the above estimate the mean value $\overline{P}$ of the potential gradient at ground level was assumed to be 150 volts per metre (1·5 v./cm.). This gives in electrostatic units (E.S.U.)

$$-4\,\pi\sigma = \overline{P} = (1 \cdot 5)/300 = 0 \cdot 005.$$

Taking the earth's radius as 64×10^7 cm., the whole charge on the earth $= 0 \cdot 005 \times 4 \times 10^{17} = 2 \times 10^{15}$, or 67×10^4 coulombs.

To get a really good value for $\overline{P}$, we ought to have results from numerous well-distributed stations, and at each station observations are wanted for the whole year. Systematic observations have, however, been taken at only a few stations, and at

most of these the numerical measures obtained may give relative values of the potential gradient at different times satisfactorily enough, but not the absolute values. Trees, buildings or other objects not insulated from the earth, lower the potential in their neighbourhood. Thus the observed values are apt to underestimate the true potential gradient unless the place of observation has been carefully chosen, and precautions have been taken to eliminate the disturbing effects due to the presence of instruments and observers.

Annual Changes.

Potential gradient, in addition to incessant irregular fluctuations, has large diurnal and annual variations. Thus a few stray observations at a particular spot may give a very erroneous idea as to the mean annual value. Even at the best equipped stations, with continuous registration, information as to the true mean annual value is hard to come by. Little uncertainty exists on fine days free from large rapid oscillations, but it is otherwise during heavy rain, and especially during thunderstorms. We have then to do with large rapid oscillations, recorded by an instrument which is not dead-beat, the indications of which may be prejudiced by the direct action of rain.

In view of the difficulty of dealing satisfactorily with highly disturbed days, few stations include these when calculating diurnal or annual variations. The practice at Kew Observatory is to deduce diurnal inequalities and mean monthly values from hourly measurements on ten quiet days a month, the results thus representing fine weather conditions. Measurements are also made on all days when possible at 3 h., 9 h., 15 h. and 21 h. The mean from these four hours, when a large number of days is included, makes a close approach to the more complete 24-hour mean. Thus an idea may be obtained of the effect on the yearly mean of deriving it from the selected quiet days by comparing this mean with that derived from the above specified 4 hours on unrestricted days. The following results were obtained for the year 1922 :—

Mean from hourly measurements on selected quiet days, 318 v./m. ; mean from measurements at 3 h., 9 h., 15 h., 21 h., omitting negative potentials, 293 v./m. ; mean from measurements at 3 h., 9 h., 15 h., 21 h., on all days of complete trace, 271 v./m.

The quiet day mean would thus appear to be in excess of the mean that would be derived if all days were included.

The extent to which negative potential gradient prevails may be gauged by the fact that at Kew during 1923—a fairly representative year—there were approximately 350 hours of negative potential, distributed among 190 days, the longest duration on any one day being 12·5 hours. Fewer days are free from negative potential at Eskdalemuir than at Kew, but in this respect Kew is likely to be the more representative station.

The following are some of the mean annual values actually obtained, most, if not all, from selected days :—

Station.	Period.	v./m.
Karasjok (Lapland)	1904	139
Eskdalemuir	1912–22	256
Potsdam	1904	242
Kew	1913–23	333
Kremsmünster (Austria)	1902	98
Tortosa (Spain)	1922	76
Cape Evans (Antarctic)	1911–12	87

The values at Eskdalemuir, Potsdam and Kew are much in excess of those at stations in both higher and lower altitudes. Defective methods or apparatus are more likely to lead to low than to high values. On the other hand, atmospheric pollution has been found to raise the potential gradient. At Kew, when the selected days for 1921 and 1922 were divided into two equal groups, representing greater and less atmospheric pollution, the mean potential gradients derived from the two groups were respectively 343 v./m. and 252 v./m. A calculation based on the impurities measured in the two groups of days led to the conclusion that the mean value for the two years in the total absence of pollution would have been only 156 v./m., as against the actually observed value of 298 v./m. As the greater portion of the earth is still free from smoke pollution, such as occurs in Britain and Germany, we seem justified in believing that the ideal clean day value for Kew represents average conditions much better than does the value actually observed.

As the greater portion of the earth's surface is sea, the earth's charge will naturally depend largely on the potential gradient at sea. According to observations taken on the Atlantic, Pacific and Indian Oceans between 1915 and 1921 on board the *Carnegie*, the surveying ship of the Carnegie Institution of Washington, the mean value at sea is more like 120 v./m. than 150 v./m. But the reduction of sea observations presents special difficulties, and much more numerous and more widely distributed observations are necessary before a satisfactory final result can be obtained.

The annual variation of potential gradient is usually large, as may be seen from the following results, which are in volts per metre, and refer to the same years as the mean annual values already given :—

	Jan.	Feb.	March.	April.	May.	June.
Eskdalemuir	323	338	271	234	200	177
Kew	482	438	405	354	272	200
Tortosa	109	89	104	82	80	62
Cape Evans . .	96	89	75	79	67	80
	July.	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Eskdalemuir	183	199	234	268	328	320
Kew	196	201	249	321	426	454
Tortosa	40	43	69	52	102	94
Cape Evans	85	78	105	90	88	107

If we regard summer and winter as each composed of four months, either May to August or November to February, we obtain the following seasonal means :-

	Winter. v./m.	Summer. v./m.
Eskdalemuir	327	190
Kew	450	217
Tortosa	98	56
Cape Evans	78	95

At the European stations, as seems generally true of the northern hemisphere, the winter mean is markedly the higher. At Cape Evans, however, it is the lower.

In discussing this apparently anomalous result, the observer, Dr. G. C. Simpson, remarked that the potential gradient had been found to be highest during summer in four previous Antarctic expeditions, and the same conclusion had been reached at two out of five stations in lower southern latitudes. If the results observed in the Antarctic are representative of the southern hemisphere, the maximum of potential gradient occurs synchronously in the two hemispheres. A result so remarkable, and if true so important, calls for investigations at a much larger number of southern stations. The smaller difference between summer and winter in the Antarctic results is also exhibited in the results obtained by the *Carnegie* at sea. This suggests that the larger difference observed at European stations may arise from the increased impurity of the atmosphere due to smoke in winter. The application, however, of a correction for pollution, while reducing substantially both the winter and the summer mean values of potential gradient at Kew, left their ratio little affected.

Daily Changes.

Potential gradient, besides a large annual variation, has also in general a large diurnal variation. A full discussion of the diurnal variation of potential gradient is out of the question. The extent to which it varies, even within the narrow limits of the British Isles, may be seen on comparing the Kew and Eskdalemuir curves in Fig. 1. Both sets refer to quiet days free from negative potential, and both refer to Greenwich mean time, which is in advance of local mean time by 1 minute at Kew and 13 minutes at Eskdalemuir. The results are in each case derived from 11 years, 9 being common to the two stations. In addition to the whole year, winter (November to February) and summer (May to August) are separately represented. At Kew a double oscillation with two distinct maxima and minima is prominent the whole year round, especially in summer. At Eskdalemuir the secondary maximum in the forenoon is distinctly visible in winter, but in summer it is represented merely by a slackening in the fall to the conspicuous minimum near noon. The tendency for the

interval between the forenoon and afternoon maxima to lengthen as the day lengthens is prominent at Kew, and recognisable at Eskdalemuir.

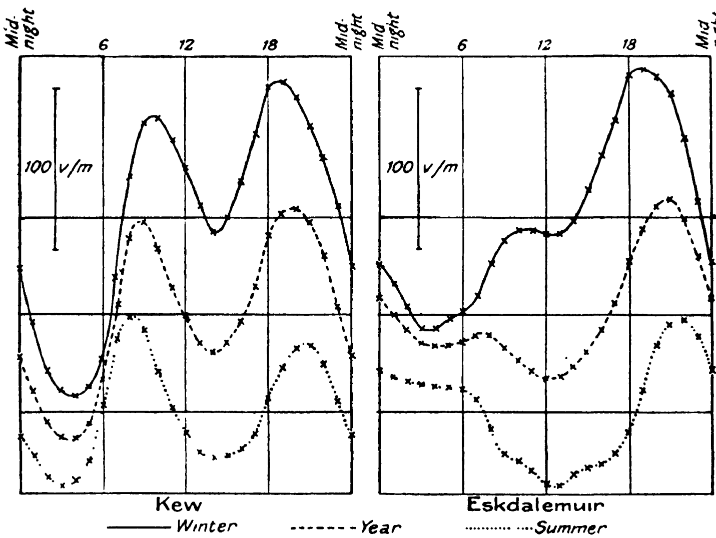

FIG. 1.

The double oscillation is unusually prominent at Kew, but is recognisable at most land stations; and most of these agree with Kew in having a prominent minimum in the early morning.

In a recent discussion, Dr. S. J. Mauchly, of the Carnegie Institution of Washington, has supported the view that the diurnal variation of potential gradient at sea follows not local time but Greenwich time—*i.e.*, that either daily extreme tends to occur simultaneously at all parts of the ocean. If this is true, even of parts of the sea remote from land, it is certainly a very unique phenomenon.

CARRYING ELECTRICITY THROUGH THE ATMOSPHERE.

The conductivity of the atmosphere and the elements on which it depends, namely, the number of free positive and negative ions, and their mobility, have undergone a good deal of investigation on the Continent, but the diurnal and annual variations of these elements and of the air-earth current are still very imperfectly ascertained. In Britain the only systematic observations have been those made at Kew Observatory on the air-earth current and the ionic charges associated with the more mobile ions. These refer to only one hour of the day, 3 p.m.

The air-earth current varies directly as the potential gradient and as the conductivity. The potential gradient at Kew at 3 p.m.

is 2·36 times as large in "winter" as in "summer"; but, taking a mean from the five years 1919–1923, the winter value of the air earth current has been only $\frac{7}{9}$ of the summer value. The conductivity must thus be three times as great in summer as in winter This is partly explained by the fact that the number of the more mobile ions, both positive and negative, in summer exceeds the corresponding number in winter in the ratio 5 : 3. It results to an even greater extent from the reduced mobility of the ions in winter, which is due at least partly to the greater impurity of the atmosphere and the consequent loading of the ions.

Effect of Rain.

Precipitation (rain, snow, etc.) is unquestionably an important vehicle for the interchange of electrical charge between the earth and its atmosphere. The most complete investigation of this subject hitherto made seems to be that carried out at Simla in 1908 by Dr. G. C. Simpson. He measured the amount of rain that fell and the charge brought down by it every two minutes. The sign as well as the amount of the charge was determined. For an aggregate fall of 76·3 cm. of rain per square centimetre of earth's surface, there was a total of 22·3 E.S.U. positive, and 7·6 E.S.U. negative electricity. Thus the mean charge per centimetre cube of rain was $+0\cdot19_3$ E.S.U., or 64×10^{-12} coulomb.

The total charge + 14·7 E.S.U. thus observed is sufficient to maintain for a whole year a current of $1\cdot5 \times 10^{-16}$ ampere per cm.^{2}. This is very similar to the supposed mean value of the fine weather air-earth current. It is, however, in the same direction as that current, so its existence only doubles the prevailing mystery.

At Simla 75 per cent. of the electricity brought down by rain was positive, and the sign was positive during 71 per cent. of the time when sensibly-charged rain fell. The proportion of positive charges increased as the rain was heavier. There were ninety-seven 2-minute intervals during which rain fell at a rate of not less than 0·56 mm. per minute, and during every one of these the sign was positive. On the other hand, of the 2-minute intervals during which rain fell at a less rate than 0·07 mm. per minute, 47 per cent. gave the negative sign, and, of the total charge recorded in these light rains, 54 per cent. was negative.

In general the charge per centimetre cube of rain was greater in light than in heavy rain. Of the 34 occasions when the charge exceeded 6 E.S.U. per centimetre cube, 20 gave a negative sign (18 of these occasions, however, were on one day); and while the highest value per centimetre cube for positive was 8 E.S.U., 15 higher values than this—ranging from 9 to 20 E.S.U. per centimetre cube—were recorded for negative charge.

Most of the rainfall recorded at Simla would be considered exceptionally heavy in temperate climates. Thus it obviously

would not be safe to infer that the predominance of positive rain experienced at Simla was true everywhere and at all times. Several other observers have, however, obtained a balance of positive charge with rain elsewhere. On 33 occasions the current measured by Dr. Simpson exceeded $3{,}000 \times 10^{-16}$ amp. per cm.^{2}, or 1,500 times the supposed mean fine weather current, the largest observed value being $10{,}000 \times 10^{-16}$ amp.

Lightning.

Another vehicle for the exchange of charges between the earth and the atmosphere, the importance of which is even more difficult to assess, is lightning. For the investigation of thunderstorm phenomena we are mainly indebted to Prof. C. T. R. Wilson. His method is based on the fact that the charge on a plate area at zero potential which can be treated as part of the earth's surface is proportional to the potential gradient at the surface. The change in the charge of the plate during the passage of a lightning stroke supplies a measure of the change in the potential gradient brought about by the discharge. Prof. Wilson's measurements refer to the integral of the changes during a time which to ordinary ideas is very short, but still may be long from the point of view of those interested in wireless atmospherics.

The significant phenomenon accompanying a flash of lightning is the change of potential gradient. The change of potential observed by Prof. Wilson was positive for 528 out of 864 flashes—*i.e.*, in 61 per cent. of the total.

Prof. Wilson's conception of an ordinary thundercloud is that it consists normally of an upper and a lower part. The charges in the two parts are of opposite sign, but there is no necessary relation between the two amounts. In most cases Prof. Wilson believes the upper charge to be positive, say, Q_2, and the lower to be negative $-Q_1$. Suppose these charges to be concentrated at points in the same vertical line, at heights H_2 and H_1 above the ground, supposed horizontal. To calculate the resulting potential we may regard the charge induced in the earth as replaced by the image charges $-Q_2$ and $+Q_1$, at depths H_2 and H_1 respectively. The (downwardly directed) force at ground level is then easily found to be

$$2Q_2H_2(H_2^2+L^2)^{-\frac{3}{2}} - 2Q_1H_1(H_1^2+L^2)^{-\frac{3}{2}}$$

where L is the horizontal distance of the point at which the force is being measured from the vertical line on which the charges are supposed located.

The force at the ground immediately under the charges is thus $-2(Q_1H_1^{-2} - Q_2H_2^{-2})$, while at a distance L, large compared with H_2, it is $2(Q_2H_2 - Q_1H_1)L^{-3}$.

As H_2 exceeds H_1, unless Q_2 and Q_1 are widely different, the force in the case supposed is downwards (as in fine weather) at a

considerable horizontal distance, but upwards immediately under the thundercloud. At some intermediate distance the force vanishes. An upwardly directed force means a negative potential gradient, and a positive charge at the earth's surface. Thus, if a discharge passed in this case between the ground and the lower cloud, it would naturally carry a positive charge from the ground to the cloud. This, it will be remembered, is what Prof. Wilson observed in 61 cases out of 100.

A lightning stroke might, of course, produce only a partial discharge of a cloud, but Prof. Wilson's observations fit in best with the view that the discharge is usually complete, or nearly so. When discharges were at a considerable distance, the potential changes observed followed in a general way the law of the inverse cube of the distance, which is that given by the above formula on the hypothesis of total discharge.

The observations really gave the product Q H. The values obtained for Q, on the hypothesis that H was 2 km., averaged about 20 coulombs. Immediately on the discharge, regeneration took place of the charge in the thundercloud, the initial rate of regeneration being very rapid. In fact, at the initial rate, the charge in the average case would have been replenished in about 7 seconds. Supposing 20 coulombs in the thundercloud, this would imply a current of some 3 amperes. The rate of replenishment fell off in reality very rapidly as the time increased, following an approximately exponential law.

For a spark to pass in air at ordinary atmospheric pressure, a voltage of 30,000 v./cm. is required. This voltage would be found at the surface of an isolated sphere of 250 metres radius charged with 20 coulombs. The presence of the earth, and the bipolarity of the cloud, will naturally have a large effect on the voltage at the surface of, say, the lower cloud, so that the above is likely to be a considerable under-estimate of the volume discharged by a lightning stroke. The changes in the potential gradient accompanying a lightning stroke are, according to Prof. Wilson, of the order of 1,000 v./m. when the distance of the flash is 10 km., and might be as high as 100,000 v./m. when a flash takes place right overhead.

The Heaviside Layer, Aurora and "Atmospherics."

An "upper conducting layer" plays a prominent part in Prof. Wilson's theoretical views. In fine weather the potential gradient falls off rapidly as we go up, and observations point to the conclusion that even at 10 km. it is practically negligible. There can thus be little further increase of potential at greater heights, and Prof. Wilson regards 10^6 volts as a liberal estimate for the higher regions of the atmosphere. Assuming considerable conductivity, we may consider the upper atmosphere as approximately at one potential. If, then, we have a thundercloud of

which the upper charge is positive, the potential at the top of that cloud, which according to Wilson is of the order 10^9 volts, is very high compared with that of the conducting layer. Lightning may pass between the ground and the lower or the upper cloud, between the lower and the upper cloud, or possibly upward from the upper cloud. In any case a considerable electrical current may pass between the upper cloud and the conducting layer. If the upper cloud is charged positively, the current will carry a positive charge to the conducting layer, and thus tend to make up for the downwardly directed fine weather current and the charge brought down by rain.

This explanation would obviously be insufficient if lightning were a rare phenomenon. While, however, a thunderstorm is a comparatively rare event at any one station in temperate latitudes, the number of thunderstorms per diem experienced by the earth as a whole must be large. Even in such a limited area as France, there are comparatively few days in the year where thunder is nowhere reported. The explanation would thus seem a possible one, but a great deal more information is required as to lightning charges in different parts of the world before a conclusion would be justified.

The existence of an upper conducting layer—or, as it is sometimes called, a Heaviside layer - is also of interest in connexion with wireless. It has been invoked, especially by Prof. W. H. Eccles, in explanation of the surprisingly great distances to which wireless signals are transmitted. The most direct evidence we have of the existence of such a layer is afforded by auroral and magnetic phenomena. The co-existence of magnetic storms and brilliant aurora is conclusive evidence that aurora is an electrical phenomenon. As Prof. Störmer's measurements have shown, the lower edge of visible aurora is usually at a height of about 100 km. Electrical currents at that height, to produce the large effects seen in magnetic storms, must be of large size, and the conductivity of the space where these currents occur must thus be high, unless we postulate a quite incredible expenditure of energy. Wireless experts seem in favour of a smaller height than 100 km. for the conducting layer, and Prof. Wilson's arguments would seem to fit in better with a lesser height. Various observers, moreover, have thought they have seen aurora at much smaller heights, but the recent precise measurements made in Norway tend to show that under normal conditions, aurora at heights below 85 km. must be very rare.

The auroral layer is certainly not a thin one, as Prof. Störmer has measured aurora at heights up to 650 km. It is also not certain that the electrical currents which produce the ordinary daily changes in terrestrial magnetism are at the same height as those which manifest themselves in aurora and magnetic storms. But, if not certain, it is at least probable that the heights are the same.

Otherwise it would be difficult to explain the fact that the regular diurnal variation increases with magnetic disturbance, and that this increase is particularly prominent in high latitudes where aurora prevails.

An increase in the amplitude of the regular diurnal magnetic changes is a prominent feature of sunspot maximum, while aurora and magnetic disturbance tend to a minimum near sunspot minimum. The natural inference is that the conductivity of the upper atmosphere increases with sunspot frequency and with magnetic disturbance. It would thus not be at all surprising if wireless phenomena showed an eleven-year period, and exhibited some dependence on aurora and magnetic disturbance. If any relation of the kind exists, it is in high magnetic latitudes that we should naturally look for it.

In view of the large changes of voltage accompanying even distant lightning strokes, it is natural to regard lightning as the probable source of wireless "atmospherics." But there are also rapid changes at least of the magnetic field during aurora.

The electrical currents visible at night as aurora doubtless exist, though invisible, during the day. But in Britain magnetic disturbance is normally greatest during the evening hours when aurora is visible. Also it is greater in the equinoctial than the summer months. Thus any disturbances associated with the electrical phenomena visible as aurora would naturally in Britain be greatest after dark and in the equinoctial months. They should also be markedly less numerous and more poorly developed near sunspot minimum than at other times. Adequate statistics as to the diurnal and seasonal variation of "atmospherics" would be hard to come by. The problem is complicated by the fact that the development of atmospherics at any given instant varies with the orientation of the receiving aerial. The observations carried out by Mr. R. A. Watson Watt for a year at Aldershot suggested a maximum of frequency in June (naturally a very quiet month magnetically) and a minimum in March. Mr. Watt's observations were, however, confined to 7 h., 13 h., and 16 h., all hours remote from the hour of maximum auroral frequency and magnetic disturbance. The diurnal and annual variations indicated by Mr. Watt's figures are by no means so prominent as we should expect if lightning flashes were the sole cause of atmospherics. Observations for several years from a variety of stations, covering adequately both day and night, would appear desirable.

In a later paper, Mr. Watt and Prof. E. V. Appleton have investigated the nature of "atmospherics." They found two principal classes which they describe as "aperiodic" and "quasi-periodic." These were about equally numerous. The aperiodic group, showing a growth and a decay period usually of similar length, had durations varying from 0·0001 to 0·055 sec., the average being 0·004 sec., but the most common only 0·001 sec. The quasi-periodic group, consisting usually of one complete

but unsymmetrical oscillation, were much less variable in length, having on the average a duration of 0·002 sec. The average amplitude of the change of field was about 0·13 v./m. in both groups. But, whereas there was no marked unbalanced transfer of electricity in the quasi-periodic group, seven out of eight of the aperiodic type carried positive electricity from the earth. This, it will be remembered, is also the direction which Prof. Wilson found most prevalent in lightning flashes.

The Earth's Electric Charge.

Little has been said here as to the numerous theories that have been advanced to account for the earth's charge, but reference may be made to one of them, namely, that the charge is due to a very penetrating radiation reaching the earth from outside, probably from the sun. An apparently fatal objection to this has been the absence of the ionisation naturally expected to accompany such a radiation. A way out of this difficulty has been suggested in a recent paper by Prof. W. F. G. Swann. His theoretical investigations lead him to the conclusion that a corpuscle travelling with a velocity which fell short of the velocity of light by 45 metres per second or less would not ionise the air it passed through. In the absence of positive knowledge, Prof. Swann was obliged to make several assumptions in his calculations, and whether these will recommend themselves to experts in the subject appears very doubtful.

Some Practical Developments.

The references we have made to atmospheric pollution, thunderstorms and wireless will have shown that atmospheric electricity has practical as well as theoretical interests. But there are two still more practical aspects which may be just glanced at. The first is the possibility that the existence of the potential gradient, entailing under normal conditions a big difference of potential between the earth's surface and the atmosphere at comparatively small heights, may be utilised practically as a source of mechanical power. The second is the possible utility of the potential gradient as a stimulus to the growth of plants. The suggestion of Lemström that the potential gradient influences growth has led to experiments in electroculture. Experiments have been made in England and elsewhere to see how crops growing under zero potential gradient compare with those grown in the ordinary earth's field. No very decisive results seem to have been obtained. It should, however, be remembered that the potential gradient above tree tops will ordinarily be very large as compared with the potential gradient at ground level. Thus atmospheric electricity might be of importance for sylviculture, without being of importance for ordinary farm crops.

A second point, which may be of significance in connexion with the high potentials used in electro-culture, is that when Nature applies high potentials and large air-earth currents to grass and ordinary crops, it is usually to the accompaniment of a liberal supply of moisture.

It is hoped that the above slight discussion of some of the phenomena of atmospheric electricity will bring home to the reader the numerous directions in which patient, intelligent, observational work is urgently wanted.

DARWINISM.

By C. Tate Regan, F.R.S.

The Evidence for Evolution.

Although many different and conflicting opinions are held as to the causes and methods of evolution, it cannot be too strongly emphasised that the evidence in favour of evolution, or descent with modification, is unassailable. Darwin showed that the facts of structure, classification, development, geographical distribution and geological succession of animals and plants were inexplicable unless there had been evolution. He gave a new impulse and new ideas to work in these branches, all of which had confirmed his conclusion, so that at the present day we are justified in saying that evolution is established. Organic evolution, indeed, is just as well established as the movement of the earth round the sun; it is an inference from many kinds of evidence, all leading to the same conclusion. This comparison is not without interest, for it may be recalled that, a few hundred years ago, the geocentric theory of the universe was generally accepted, and that when the idea that the earth moved round the sun was first put forward, it was opposed for very much the same reasons that the idea of evolution was opposed later on.

Before Darwin's time naturalists had made great progress in the classification of organisms according to their structure, arranging them in groups within groups, always striving towards a Natural System, expressing the true affinities of one form to another. Darwin pointed out that the Natural System is founded on descent with modification, that the characters considered to show true affinity between species are those inherited from a common ancestor, and that all true classification is genealogical.

Thus the expression of relationships has become the primary aim of classification, and the method of study is an attempt to estimate the meaning of resemblances and differences in structure—to what extent these may be due to the nearness or

remoteness of a common ancestor, to what extent to similarities or dissimilarities of habits and environment.

Related forms, although very dissimilar when adult, are often quite alike in the early stages of their development. The study of embryology has led to the formulation of the statement that the development of the individual tends to repeat the history of the race, the adult stage of the ancestral form being represented at an earlier stage in its modified descendants. The value of this generalisation has sometimes been disputed, but its truth is well shown by such series as the fossil corals from successive horizons studied by Mr. R. G. Carruthers. In these the young stages of the form found in one horizon are structurally similar to the adults of that found in the earlier horizon immediately below it.

Darwin insisted on the imperfection of the geological record, and pointed out that we could not expect to find in the rocks a large number of transitional forms connecting the past and present species of a group. Although great progress has been made in palæontology, we still know but a minute fraction of the vast number of forms of life that must have inhabited the earth in former times. The value of the evidence from palæontology lies not in its completeness, but in the fact that it all points in the same direction. In recent years lineages, or lines of descent, have been established; for example, the ancestry of the elephant has been traced back to a primitive hoofed animal, very similar in appearance to a tapir, found in the upper Eocene beds of Egypt. Also many connecting forms have been discovered; for example, extinct types of man, with skulls possessing ape-like features that have been lost in modern man.

The Mammals of Australia may be used to illustrate how evolution throws light on the facts of geographical distribution. The Monotremes, the Duck-billed Platypus and the Spiny Anteaters, found in Australia, Tasmania and New Guinea, are the only survivors of a primitive group that appears to have become extinct elsewhere millions of years ago. In other parts of the world the placental Mammals are dominant, but these, except for a dog introduced by man, and a few kinds of small rodents, which appear to have made their way over the sea on floating timber, have never reached Australia, which was evidently cut off by sea from the rest of the world before they developed. The Marsupials, a much more advanced type than the Monotremes, but ancient, and in some ways more primitive than the placental Mammals, have, in the absence of these, developed in the Australian region into a number of different types, Kangaroos, Thylacines, Bandicoots, Wombats, etc., which have doubtless caused the extinction of the less highly organised Monotremes, with the exception of the Platypus, which is aquatic, and so occupies a place that no Marsupial seems to have tried to fill, and the Anteater, which is protected by its covering of hedgehog-like spines, and by its burrowing habits.

Theories of Evolution.

Darwin, after patiently accumulating the evidence and considering it for many years, put forward the theory that evolution has been effected chiefly through the natural selection of slight, favourable variations, aided in an important manner by the inherited effects of use and disuse, and in an unimportant manner, in relation to adaptive structures, by the direct action of the environment and by variations which seem to us in our ignorance to arise spontaneously. The foundation of the Natural Selection Theory is that animals and plants are eminently variable, and that in every generation many more are born than can possibly come to maturity; consequently it was suggested that in the struggle for existence, those best fitted to survive would do so, and would leave descendants more or less like themselves, the fittest of whom would again be selected.

Darwin considered that natural selection was the most important, but not the only means of modification. To-day biologists tend to split up into schools, one of which claims that natural selection alone has been operative, whereas others deny the importance of natural selection; of these, one attributes most to the inherited effects of use and disuse and of the direct action of the environment, and another denies that these effects are inherited and relies on those variations which, as Darwin said, seem to us in our ignorance to arise spontaneously.

Biology is now so vast a subject that one man cannot hope to become an authority on more than one branch of it; all biologists are specialists, and their outlook on evolution seems to be to a considerable extent determined by the nature of their special studies.

In his essay on mimicry, Prof. Poulton shows how well the facts may be explained by the Theory of Natural Selection. Dr. Gahan's work on mimicry in beetles is also most instructive. He states that mimicry occurs only in day-flying beetles, those that fly by night being generally prôtectively coloured, resembling the objects on which they rest during the day. He contrasts the uniformity of one family of beetles with the diversity of another. The Lycidæ, easily recognised by their form and colour, are protected by a distasteful secretion, and wherever they occur are mimicked by day-flying beetles of other families and by other insects, which thus get the advantage of being mistaken for them. The Cerambycidæ are not protected by a distasteful secretion, and exhibit the greatest diversity, mimicking other insects; even closely related forms are quite dissimilar, some resembling stinging insects, such as wasps, others noxious beetles, etc. Here we have a condition of affairs that cannot possibly be explained as accidental, nor as the result of use and disuse or of the direct action of the environment; but it could have been brought about by natural selection.

Let us next consider the Dodo, a flightless bird that formerly inhabited the island of Mauritius. It was about as large as a goose, a heavy, clumsy bird, with very small wings and with the tail represented by a little tuft of feathers. Structurally it shows relationship to the pigeons, and there can be little doubt that its ancestors were pigeon-like birds that flew to Mauritius. Here they found that food was plentiful and that there were no carnivorous animals to attack them, and in course of time their descendants lost the power of flight and grew larger, whilst their wings and tail decreased in size. About 300 years ago Europeans introduced pigs and dogs into Mauritius, and the Dodo, unable to cope with these new invaders, soon became extinct.

If the evolution of the Dodo can be explained in terms of the Natural Selection Theory, it must be admitted that the explanation is not very convincing, and this example is given here as typical of many that lead to the conclusion that the effects of use and disuse are inherited and are of importance in evolution. The opponents of this conclusion demand experimental proof, but it is obvious that the attempt to repeat the operations of Nature might involve an experiment that would last for thousands of years; nevertheless, there are signs that experimental proof may yet be forthcoming.

The non-adaptive spontaneous variations, which Darwin considered might be of some importance in specific differentiation, if their unknown cause were sufficiently widespread, have come into prominence in recent years, as they have been especially studied by those engaged in experimental breeding. New varieties, differing from the normal in some well-marked character, suddenly make their appearance; if these are crossed with the parent form, and the hybrids so obtained are bred together, the new character appears intact in a certain proportion of the next generation. In experimental breeding it has been found possible to form new combinations of characters that are inherited in this definite manner, so that striking novelties have been produced. But now it seems to be admitted that this work does not throw much light on evolution, that the production of these novelties has no relation to the origin of species. Indeed, there is strong reason for believing that in Nature the first step in the origin of a new species is not the appearance of a new character, but the formation of a community with new habits, or in a new or a restricted environment.

The present writer's attitude towards these matters may be illustrated by an example from his own work. Shad are fishes of the herring family that enter rivers to breed. The Twaite Shad (*Alosa finta*) of the Atlantic coasts of Europe is represented in Killarney by a form that differs from it in its smaller size, deeper body, and more numerous gill-rakers—projections from the gill-arches that intercept the food. The Killarney Shad never leaves the lake and must have evolved from Twaite Shad that formed a lacustrine colony, probably founded by young that preferred

staying in the lake to going to the sea. We have good reason to suppose that this evolution has taken place since the Glacial Period—say, within the last 100,000 years—for the presence of a Char* in Killarney proves that in Glacial times the sea off the coast of Kerry was cold, and the Twaite Shad and its allies are fishes of the Mediterranean and the warmer parts of the North Atlantic. Also, it is a legitimate inference that the increased number of gill-rakers in the Killarney Shad is related to a diet of minute Crustacea, and that its form and size may be related to its restricted environment and changed habits. Here, then, we see what has happened, and where and when it has happened; we have some evidence as to why; the problem that remains to be solved is, how? Whether that or similar problems could be solved by experimental attempts to repeat the operations of Nature is an open question, but such experiments would at least be on the right lines.

* Char are Salmonoid fishes of the Arctic Ocean; they breed in fresh water and often form permanent colonies in lakes.

INSECT MIMICRY AND THE DARWINIAN THEORY OF NATURAL SELECTION.

By Prof. E. B. POULTON, F.R.S.

The superficial resemblances between insects constantly attracted the attention of the older naturalists, as we realise from the names they gave when they called certain moths "bee-like," "wasp-like," etc. It was the same with resemblance to surroundings. The fine old naturalist, W. J. Burchell, writing more than a hundred years ago of his travels in the interior of South Africa, described a grasshopper which exactly resembled a stone, and also fleshy plants of the Karoo which were hidden in the same way. He fully recognised the benefit conferred by this likeness, but held the common belief of his day that insect and plant came into existence exactly as we see them, and that their resemblances were part of "the harmony with which they have been adapted by the Creator to each other and to the situations in which they are found."

The appearance of Darwin's "Origin of Species" in 1859 brought clear evidence that animals and plants had reached their present state by a process of evolution, and that the main motive cause had been Natural Selection or the Survival of the Fittest, acting upon hereditary variations. One of the first problems to which these principles came to be applied was insect mimicry and the protective resemblances or concealing colours and shapes of insects—both resemblances so widespread and evident in Nature that the failure to explain them on Darwinian principles would have meant the breakdown of the principles themselves. Insect mimicry and insect concealment became test problems. If produced by Natural Selection, these resemblances must be beneficial and must have been attained by transition from different and less beneficial stages.

It is necessary at the outset to clear away certain misconceptions which here arise from the word "mimicry," used in ordinary speech to signify conscious imitation. As used technically for these deceptive superficial resemblances, conscious imitation is out of the question. No insect "by taking thought" can effect any change in its own appearance. Mimicry is akin to protective resemblance, and is sometimes employed to include the latter; but it is convenient to keep the two separate because they lead to such different kinds of appearance. In mimicry, an insect resembles another, the model, which possesses some special defence, such as a sting, an unpleasant taste or smell, etc., and advertises its powers by conspicuous warning colours. The mimic therefore becomes itself conspicuous. In protective resemblance, on the contrary, an insect resembles something, such as earth or bark, of no interest to its enemies, and in resembling it becomes concealed.

Bates's Interpretation of Mimicry.

Returning to the relation between Mimicry and Natural Selection, it must have been obvious to naturalists for many years that the resemblance of a stingless moth or fly to a bee or wasp is likely to be advantageous. It was otherwise with the likeness between many butterflies and day-flying moths collected by H. W. Bates in the Amazon Valley—striking likenesses of colour and pattern in each locality, all changing together, "as it were with the touch of an enchanter's wand," in passing from one area to another. The late Dr. F. D. Godman has told us that Bates did not solve this problem in the tropics. The solution came after studying his collection at home and reflecting on his memories of the living insects. In November, 1861, just two years after the publication of the "Origin of Species," he read before the Linnean Society his classical paper in which it was shown that the imitated butterflies or "models" were specially abundant, conspicuous and slow-flying, and belonged to groups with these characteristics, while the "mimics"—members of several widely separated groups—had departed from the colours and patterns still borne by their non-mimetic allies.

A few years later, in 1866, A. R. Wallace showed that Bates's interpretation was valid for the Tropical East; and, again in a few years, Roland Trimen proved that it held in Africa. All three memoirs were published in the "Transactions" of the Linnean Society, and the last mentioned, appearing in 1870, showed for the first time that three Swallowtail butterflies with entirely different patterns, and without "tails" to the hind wings, were the females of a fourth Swallowtail (*Papilio dardanus*) which bore "tails", and was of a still more divergent pattern. All four had been described as different

species. Trimen further showed that in Madagascar a closely allied male had a tailed female very like itself, and that on the mainland of Africa the "tails" had been lost and different patterns gained by the females in mimicry of three different species of the tailless group Danainæ which provides the chief models for mimicry in the East, and is closely allied to the chief models of tropical America.

Trimen's conclusions were received with incredulity, and indeed contempt by some of the older naturalists; but he lived to see them everywhere accepted, and put beyond the possibility of doubt by breeding the males and all three female forms in one family produced by a known female parent.

Müllerian Mimicry.

Bates, in the great paper already referred to, directed attention to the fact that butterflies belonging to the groups which supply the models also mimic each other, and this puzzled him. The interpretation came in 1878, when Fritz Müller, a German naturalist living in Brazil and deeply influenced by the "Origin of Species" and by correspondence with Darwin, brought forward the theory which has since been known as Müllerian mimicry. He then showed the advantage of a resemblance between unpalatable conspicuous insects, because it reduces the number of warning patterns which must be learnt by enemies and the number of injuries inflicted in learning them.

Batesian mimicry is like the action of a struggling unscrupulous firm which imitates the trade-mark or advertisement of a successful house. Müllerian mimicry is like the action of a group of powerful firms which become still better known at a lessened cost by combined advertisement.

The decision, whether any mimic is Batesian or Müllerian, is in some instances easy, in others difficult, and opinions are divided as to the relative importance of the two theories. When the allies of a mimetic species are well concealed by protective resemblance, then the mimic is most probably Batesian; when the allies are specially protected and warningly-coloured, then the mimic is probably Müllerian, and has merely exchanged one warning pattern for another. Again, a large proportion of mimetic species are, like *Papilio dardanus*, only mimetic in the female sex, the original pattern of the female being retained by the male. Here the appearance of the male, and especially of its under-surface pattern, helps us to decide whether the female is a Batesian or a Müllerian mimic.

The prevalence of mimicry in the female was explained by A. R. Wallace by the greater needs of that sex—their greater weight and slower flight, and the necessity for them to alight and lay their eggs. Another co-operating explanation was suggested much later, namely, that the females are more variable than the

males, and thus produce the requisite changes of pattern more 'reely.

Origin of Mimicry.

Butterflies and day-flying moths are especially suitable for the study of mimicry, because the resemblances are chiefly shown in the colours and patterns on the broad surface of their wings, both colours and patterns being very variable, and thus affording material for rapid change by the operation of Natural Selection. But the same phenomena are conspicuous in other groups of insects, such as the beetles. We find among the beetles, as among the butterflies and moths, that the models belong to the distasteful warningly coloured groups, and that members of these tend to mimic each other, as well as to be mimicked by species of less powerful groups.

There can be little doubt that Mendelian heredity has been of great importance in the origin of mimicry, diminishing the "swamping effect of intercrossing" between the parent form and the incipient mimic and between the different fully formed mimics belonging to one species, as in *P. dardanus*. There is also a considerable body of facts which suggests that Mendelian heredity does actually operate in this and other mimetic species, the most complete evidence being that obtained by Mr. J. C. F. Fryer by his breeding experiments on *Papilio polytes*. This species, in Ceylon, where the experiments were conducted, has three forms of female, one like the male and two resembling other Swallowtails which belong to a distasteful group. The Mendelian relationship was found to exist between these three females.

Mimicry and Geographical Distribution.

It is in the facts of geographical distribution that we find the most conclusive evidence of the production of mimicry by Natural Selection. Two Danaine butterflies in America belong to an Old World group, and are evidently recent invaders by way of the north. In temperate North America they have met the natives of the Northern Belt, among them the White Admirals, allied to our own well-known species *L. sybilla*. If, therefore, mimetic resemblance is, as some have supposed, the common result of common causes associated with locality, the invader ought to have come to resemble the ancient resident, but as a matter of fact the resident has lost its original pattern and mimics the invader. The change, although immense, so far as the pattern is concerned, is so superficial and recent that the early stages are entirely unaffected, and the mimic can interbreed with another unchanged North American White Admiral, producing an intermediate hybrid—an experiment successfully carried out by Mr. W. L. W. Field.

The Pseudacræas of Tropical Africa, nearly all of them mimetic in both sexes, are butterflies closely allied to the White Admirals. A species in Uganda, *P. eurytus*, is a very complicated example of mimicry, for this single species includes in the same locality three different forms, two with sexes alike, mimicking two Acræine species with sexes alike, one with sexes different, mimicking the corresponding sexes of another Acræine. The fact that all these mimics are one species was proved by breeding by Dr. G. D. H. Carpenter. Now in Uganda intermediates between these three forms of *eurytus* are rare, whereas on some of the islands in Lake Victoria they are very common, and Dr. Carpenter, who proved this fact, found that on these same islands the models are, for some unknown reason, rarer than their mimics. The facts suggest strongly that there is more severe extinction of intermediates in the presence of abundant models, but less severe when models are few.

Mimicry Produced in Various Ways.

Further convincing evidence of the production of mimetic likeness by the operation of Natural Selection is provided by a comparison of the different methods by which a resemblance to formidable insects, such as wasps and ants, has been attained. The variations which offer the possible beginnings of such a likeness are determined by the present constitution of each species, and this again has been determined by its past history. Great differences in the method of resemblance are therefore to be expected and are found. In some flies the slender " waist " of a wasp is represented by an actual narrowing of the body; in certain beetles by a patch of white which " paints out " the superfluous thickness—a device very elaborately carried out in the young stages of an African long-horned grasshopper, which lives among green leaves and has the un-antlike parts of its body coloured green, the antlike parts black.

The likeness requires astonishing readjustments when the mimicking animal is widely different from its model. Thus many small spiders mimic ants; but spiders are not insects, having no antennæ, having eight legs instead of six, and the body divided into two sections instead of three. A North American spider observed by Dr. and Mrs. Peckham got over these difficulties by holding up one pair of legs to represent antennæ and by developing a groove across one of the body sections, making it look like two.

Mimicry in Movement.

Mimetic likeness to be efficient nearly always demands appropriate movements, and these are often the most important part of

the likeness, and sometimes the probable starting-point. Thus beetles which in the cabinet do not at all closely resemble a wasp may be convincingly wasplike in the rapidity and jerkiness of their movements. This is true of our British wasp-beetle and of a rather similar Brazilian species of which Burchell wrote on his South American journey nearly 100 years ago: "It runs rapidly like an ichneumon or wasp, of which it has the appearance." A note by the same naturalist on a small Brazilian spider suggests that the first stage of mimicry was produced in this way: "Black . . . . runs and seems like an ant with large extended jaws." Now this spider does not belong to a group known to include antlike species, and Burchell's observation suggests, as Mr. R. I. Pocock has pointed out, "that the perfect imitation in shape, as well as in movement, seen in many species was started in forms of an appropriate size and colour by the mimicry of movement alone."

Mimicry and Protective Resemblance Restricted to the Visible Parts of the Body.

Of all the methods by which both mimicry and protective resemblance are produced, the most remarkable and the most convincing as evidence for the operation of Natural Selection is that followed by tropical American insects allied to the Cicadas and our too well-known Greenfly. It is only because these insects – the Membracidæ—are all of them small that the examples are unfamiliar and the lessons they teach unknown to many who are interested in the subject. The body of these little insects is shaped much like that of the Greenfly, but it is completely hidden when looked at from above by a covering shield, which is developed from the body-ring behind the head and grows backwards. Therefore, when the insect is concealed by resembling some object such as a thorn or when it mimics an ant, the deceptive likeness to be of any use must appear in the covering shield, and not in the hidden body; and this is exactly what has happened.

The criticism has been urged by Jacobi that these insects, when disturbed, leap like their relatives, the Froghoppers, and therefore the mimicry of an ant is meaningless. This is a good example of the kind of objection often raised against the theory of mimicry. But, if a hopping insect comes to resemble an ant, it still stands to gain by keeping its older means of escape when the newer one is seen through, or when it is attacked by the enemies of ants.

Selection by the Attacks of Enemies.

Another objection often brought forward, especially against the theory of mimicry as applied to butterflies, is the assertion that these insects are rarely attacked, if at all, by birds—the only

enemies which are believed to cause first the growth, and then the maintenance, of a deceptive resemblance to the model, by destroying on the average more of the less like and fewer of the more like in each generation. The critics have especially relied upon the insufficiency of direct evidence of such attacks, and the almost complete absence of butterfly remains from the stomachs of an immense number of American birds which were examined in order to determine the nature of their food.

In reply to the former objection, Dr. G. A. K. Marshall collected and published in 1909 all the observations recorded up to that date, and proved that the evidence was much stronger than had been supposed. Furthermore, attention having been thus directed to the subject, many naturalists, especially Mr. C. F. M. Swynnerton, Dr. G. D. H. Carpenter, and Mr. W. A. Lamborn, made a special study of the relation between birds and butterflies in various parts of Africa, and soon produced abundant positive evidence. Mr. Swynnerton and Mr. Lamborn also demonstrated the frequent presence of birds' beak-marks upon the wings of butterflies, marks which afford the strongest circumstantial evidence of attack. Beautiful examples of these impressions of beaks on Fijian butterflies have still more recently been received from Mr. H. W. Simmonds.

As regards the objection founded on American birds, Mr. Swynnerton has proved, and Mr. Lamborn has confirmed, that the digestion of birds is remarkably rapid, and that a butterfly is quickly reduced to a condition in which it can only be recognised by means of the compound microscope.

The facts of mimicry and protective resemblances are now patent to all, and no valid interpretation of these facts except that which is based on the theory of Natural Selection has ever been offered.

LIFE IN THE SEA.

By DR. E. J. ALLEN, F.R.S., Director of the Marine Biological Laboratory, Plymouth.

For the biologist there has always been a peculiar fascination in the study of life in the sea. There are good reasons for thinking that it was in the sea that life on our earth had its origin. It is there that we see life in its most perfect grace of form and movement, with the simplest adaptations of means to ends, and with the least interference from the ravages of modern man. Much effort has been directed in recent times to the scientific study of the relations which exist between the living organisms of the sea and their physical surroundings, as well as to the study of the inter-relations of these plants and animals among themselves. As on the land, so in the sea, the life of the animals is directly or indirectly dependent upon plant-life; and indeed it is of the essential nature of an animal that it derives its nourishment from previously formed organic or living material from the body of a plant or of another animal already in existence. The plants of the sea, on the other hand, obtain their food directly from dissolved inorganic or non-living materials which they build up into living substance under the influence of sunlight, the sunlight supplying the power or energy required for the building process.

The plants of the sea which are most generally known are the brown and red sea-weeds, but these do not extend to any great depth, as they are all plants which flourish only when fixed to some solid object on the sea-floor. They therefore die out when the depth of water exceeds about 15 fathoms, as below that depth sufficient light cannot penetrate to enable them to grow. These brown and red sea-weeds are thus confined to a comparatively narrow belt or zone around the coasts, and furnish only a small fraction of the whole vegetable food-supply of the sea. The main supply is provided by vast multitudes of minute, microscopic plants, which may be thought of as floating like a fine, brownish-green dust in the surface-waters of the ocean. The great efficiency

of this arrangement will at once be realised, for these innumerable, fine particles of living plant-substance offer the greatest possible surface for gathering from the surrounding sea-water the food-materials they require, as well as for receiving the light from the sun. It permits of the maximum quantity of living plant material being built up, so long as the light of the sun continues. By far the greater part of these floating plants live in the top 15 or 20 fathoms of water, but they may be found in smaller numbers to a depth of 100 fathoms.

Intermingled with the minute plants and feeding on them are myriads of small animals, of which the larger number belong to the group of crustacea, the group to which the shrimps and prawns, and the crabs and lobsters, belong. Jelly-fishes, transparent worms, young molluscs, as well as the glass-clear eggs and the minute larvæ and young stages of fishes, form part of this great assemblage of microscopic floating life, which, animals and plants together, is known by the general name of "plankton." A curious and interesting feature is that the animals of the plankton undergo daily vertical migrations, being found nearer the bottom of the sea during the daylight hours and ascending towards the surface waters during the night. Thus during the day the plants hold the field in the surface waters, and are busy manufacturing food substance under the influence of sunlight. During the night the plankton animals ascend from the bottom layers to utilise the food which has been produced.

The plankton animals become the food of two other classes of marine animals, which eat them with avidity. These are (1) the freely swimming or pelagic fishes, such as the herring, the mackerel and the pilchard, and (2) the bottom-living animals (*benthos*), which include many kinds of small crustaceans, creeping and burrowing shell-fish or molluscs, marine worms, and many fixed animals, growing on stones and shells, such as corals, sea-anemones and their allies.

The bottom-living animals, especially the crustacea, molluscs and worms, to which reference has just been made, are the principal food of those fishes for the capture of which our great trawl fisheries are organised : fishes such as the plaice, the sole, the haddock, the cod and the ray, and their interest and importance is therefore great. Their habits are very varied and they possess many elaborate mechanisms and devices for the capture of their minute floating food. Quantitative estimates have shown clearly that the abundance of some of these bottom-living animals on a particular fishing bank may vary greatly from year to year, and such variations without doubt exert a considerable influence on the abundance of fish in the locality.

We have already seen that the pelagic fishes, such as herring, mackerel and pilchard, feed directly on the animals of the plankton. Another large class of fishes are found, which support themselves by feeding on these pelagic fishes, as well as upon those fishes

which feed on the bottom-living animals. In this class are the hake, the tunny, the turbot, the dogfishes, and the sharks. Seals and some whales also consume large quantities of pelagic fish. It will be seen, however, that with these animals, also, the food-chain leads us back ultimately to the minute plants building up their food-substance under the influence of sunlight in the surface waters.

In describing the distribution of marine animal and plant life, it is usual to distinguish a number of zones or regions each with its particular group of species. We have first the tidal zone, where the conditions of life are severe and exacting. Only such organisms can survive here as are specially adapted to withstand the battering of the waves, and the withdrawal of the water when the tide recedes, with the consequent exposure to great extremes of temperature.

Beyond this tidal zone is the zone of the brown and red sea-weeds, where wave action is still an important factor and the amount of light reaching the bottom is sufficient for vigorous plant growth. These sea-weeds afford food and shelter for a large number of animals specially adapted to live under the conditions existing in the zone.

In still deeper water, extending from about 15 fathoms to 100 fathoms, is a third region, which comprises the greater part of the "continental shelf," the broad area which borders the continental land masses and over which the sea is comparatively shallow. The seaward edge of this continental shelf is abrupt and depths increase rapidly from 100 to 1,000 fathoms, which is already the region of the deep sea.

It is the large region of the continental shelf, between 15 and 100 fathoms, that supports life in most abundance and variety, and it is here that the great commercial fisheries are carried on. The conditions of life remain fairly uniform. The action of the waves, however great at the surface, has but slight effect on the bottom; the movement of the water due to tidal and other currents, though persistent, is not violent, and changes of temperature are limited in extent and take place slowly. The water is well provided with the food substances necessary for plant growth, these substances being brought into it by the rivers and other drainage water from the land, some of them also, especially the phosphates, being obtained by solution from the sea-floor. The two factors influencing growth which are most subject to change from season to season and from year to year are (1) the amount of light which enters the water, and (2) the movements of the water masses due to the set of the great ocean currents.

It is well known that, notwithstanding the comparative uniformity of the physical conditions in this region, its living organisms, and particularly the fishes, are subject to extensive fluctuations, some years giving an abundant yield, whilst in

other years the harvest is poor. Much recent research has been directed to an examination of the extent and of the causes of the variations in the quantities of fish present on the fishing grounds, and it is becoming increasingly clear that a great deal depends upon the success or failure in any year of the eggs and young brood. A successful brood-year results in a good fishery four or five years later, and this success may persist for several further years as the fishes continue to grow.

The age of any particular fish can now be determined with considerable certainty by an examination of the markings on the scales, which give a record of the fish's growth, or by an examination of the seasonal rings in the otoliths or ear-stones—small calcareous bodies found in connexion with the ear. It is therefore possible in the case of a shoal of fish to discover in what year or years the individual fishes were born. In this way we can follow the fishes of a successful brood-year for quite a number of years and determine the extent to which they influence the fishery. One of the most striking suggestions which has been made to account for the great differences in the survival of the brood in different years is that, in a successful year, the spring crop of minute planktonic food on which the young fish larvæ feed has been produced and is present in the water at the time when the mouths of the little fishes open and they are ready to begin to feed. A year would be unsuccessful if the production of the small food organisms were delayed beyond the time when the fishes were ready to feed. Other factors which would influence the success or failure of the brood are the set of the current, which might drift the eggs and larvæ into unsuitable situations, and the presence in exceptional abundance of such enemies of the eggs and larvæ as devour them.

In the last of the regions we are considering—the deep sea—the conditions under which the bottom-living organisms exist are remarkably uniform and in many ways not too favourable for animal life. Yet in the greatest depths which have been sounded, depths as great as 5,000 fathoms (between 5 and 6 miles), living animals are still found. The temperature at these depths approaches the freezing-point of water and is practically constant. The pressure is very high, but, being the same within and without the bodies of the animals, produces no injurious effects. Any movement of the water will be at the most an exceedingly slow current creeping along the sea-floor. No sunlight can penetrate to such depths, and the only light is that produced by the phosphorescent organs of the animals themselves. The food on which these deep-sea creatures live must be derived from the bodies of animals living in the layers above them, and through a chain or succession of food organisms must depend ultimately, as in other regions of the sea, upon the microscopic plant life which flourishes in the sunlit surface layers.

THE ORIGIN OF MAN.

By Sir Arthur Smith Woodward, F.R.S.

Relationship between Man and the Apes.

There are many structures in the human body not specially adapted for present use, which can only be satisfactorily explained by supposing that man is descended from animals which once lived in trees. The structures are so numerous and so striking that a few years ago Prof. F. Wood Jones wrote a whole book about them entitled "Arboreal Man." It has indeed been said that, if there had been no trees in the world, there could never have been man in his present form.

If this inference be correct, we naturally look to the apes and monkeys of the present day as affording the best idea of the ancestors which we suppose to have existed. We thus, on strictly scientific grounds, recognise a relationship between man and apes, which has long been fancifully imagined by speculators who have merely been familiar with their external appearance. Science, however, would not admit that any of the existing apes are the unaltered descendants of those which, ages ago, gave rise to man. Just as man has gradually become a perfect biped, adapted for an easy upright gait when walking on the ground, so the apes have acquired an increasingly effective adaptation for swinging about in trees. Just as man has lost the power of his jaws in proportion as his hands have become more mobile, so the apes have acquired more powerful jaws and teeth both to increase the efficiency of their feeding and to improve their means of offence and defence. Science, indeed, points to a remote common ancestor of man and apes which might, by changes in two divergent directions, become either one or the other. This ancestor, of course, would be popularly described as an ape if it happened to be still living, but it would be very different from any modern ape. It would be less forbidding in aspect—more like the comparatively fascinating baby of the modern ape.

Unfortunately, of animals which formerly lived in the world, we scarcely ever find more than the hard parts. Of ancestral apes and man we can only expect to discover the bones and teeth. The nature of the soft parts, therefore, can only be inferred from the shape and markings of the bones. In fact, in searching for ancestors, the skeleton alone concerns us.

Ancestral Apes.

Very little is actually known about the ancestral apes. The oldest remains are some comparatively small lower jaws, with feeble canine (or corner) teeth, from Egypt. The next in antiquity are jaws and teeth of gibbons and of apes as large as a chimpanzee from central Europe, France, and Spain. Of the skeleton of these only one thigh-bone has been discovered. Jaws and teeth of more numerous species of apes occur in India. An imperfect skull of a very young individual with milk teeth has also been found in a limestone of unknown age at Taungs in Bechuanaland, South Africa. The bony face and teeth of this specimen, however, differ in no essential respects from those of a young modern ape, and the cast of its brain-cavity is too much crushed for satisfactory comparison.

Points of Contrast.

The skeleton in both apes and man happens to be very characteristic and it is easy to distinguish the former from the latter. First, in all the apes the brain-case is comparatively small, and the face very large, often prominent; in modern man the brain-case is large and beautifully domed, while the face is comparatively small. Secondly, most of the apes have relatively large and prominent bony brow-ridges when they are full-grown; modern man lacks such brow-ridges. Thirdly, in all the apes the bony chin is receding, and the canine (or corner) teeth are relatively large and interlocking, as in a dog or cat; in modern man the bony chin is a little prominent at its lower edge, and the canine teeth are neither large nor interlocking—they are in an even series with the rest of the teeth. Fourthly, in all the apes the backbone is nearly straight—it is so even in the gibbons, which can run swiftly on their hind limbs; in modern man the backbone has a beautiful S-shaped curvature to produce the elasticity which is needed for a comfortable upright gait. Fifthly, in all existing apes, at least, the arms are relatively much longer than in man, and the great toe is as well adapted for grasping as the thumb. Sixthly, in the apes, as a rule, the thigh-bone is somewhat arched, and the shin-bone comparatively short and stout, in adaptation to the crouching gait; in upstanding modern man the thigh-bone is nearly straight.

If the theory of man's origin in an ape-like ancestor is well founded, the older the human skeletons that we find buried in the earth, the more closely they should approach ape-skeletons in the distinctive features just enumerated. Among the fossils there should indeed be "missing links." The study of other fossil animals leads us to suppose that we shall not find a single graduated series of missing links, but a multitude of forms of approach of the human frame to the ape-condition. We must infer, in short, that existing modern man is the triumphant survivor of many tentative advances towards a being with an overgrown and elaborate brain which should dominate and increasingly control the rest of Nature.

Early Man in Java.

The great difficulty is, that very few remains of man's ancestors have been discovered which date back before the time when he had so far progressed as to acquire ideas of a future life and hence to bury his dead in security. Before that time, human remains could be preserved only when an individual happened to fall into a hole or into a river or lake where the body could be covered up with sand or gravel or mud. Hitherto, the remains of not more than three such accidents have been discovered, and even in these cases only fragments of the skeletons have been preserved, so that we have very little material for the investigation of the subject.

The first of the discoveries of early man just mentioned was made by Prof. Eugène Dubois, in 1892, in an old river deposit in Java, which also contained the remains of extinct kinds of elephant and rhinoceros and other animals closely related to those still living in the East Indies. The principal fragment recovered is the top of a skull as large as that of a small man, with immense ape-like bony brow-ridges instead of the usual human forehead, but with impressions of a brain which is said to have been essentially human. Two associated teeth are not completely human, but in some ways resemble those of the little gibbon which still lives in the forests of Java. A thigh-bone, which is rather disappointing as being affected by disease at the upper end, is as straight as that of a man or a gibbon, and implies the possibility of an upright gait. If all these remains belong to one individual, as seems most probable, they represent either an ancestral man who approached the apes in his brow-ridges and teeth, or a gigantic gibbon which had an unusually enlarged brain. In any case, the being was well named *Pithecanthropus*—the "ape man"—by Prof. Dubois, who was justified in claiming it as one of the "missing links." The specimens are now in the Teyler Museum at Haarlem, in Holland.

Heidelberg Man.

The second discovery, which seems to date back to the time before man buried his dead, was made in a thick bed of sand

deposited by a river at Mauer, near Heidelberg, in Germany, and was described by the late Prof. Otto Schoetensack in 1907. It consists solely of a lower jaw, which was found in association with the bones and teeth of elephant, rhinoceros, hippopotamus, and other animals which are known to have lived in Europe at the beginning of the Pleistocene period of geologists. The jaw is astonishingly large and massive, and, though essentially human, it differs from every known human jaw in the backward slope of the bony chin, which in this respect approaches that of the ape. At the same time it contains typically human teeth in even series, without any enlargement or prominence of the canines. The fossil thus seems to represent an extinct species of man, *Homo heidelbergensis*, who still retained the retreating bony chin. It is now in the Geological Museum of the University of Heidelberg.

Piltdown Man.

The third very early accident to a primitive human being was revealed in an old river-gravel at Piltdown, Sussex, by the late Mr. Charles Dawson in 1912. This gravel occurs in the Wealden country about midway between the southern chalk downs and the sandstone ridge on which Crowborough is situated. It contains many waterworn flints which were derived from the chalk, and as no river in that part of Sussex could now bring them to the Piltdown district, it evidently dates back to a time when the local topography was entirely different from that of the present. It also contains fragments of elephant, hippopotamus, and other animals, which show that it dates back at least to the beginning of the Pleistocene period.

The only fragments of a human skeleton hitherto discovered are the greater part of a skull and nearly half of a lower jaw with two molars and a canine tooth. The skull agrees with that in some existing low races of men in being remarkably thick, but it is unique in having a very fine spongy texture, which would make it highly resistant to blows. It is as destitute of bony brow-ridges as the skull of modern man, with a good forehead, but the crown of the head is less domed than usual, and the hinder or occipital part remarkably low and broad. The brain must have been essentially human, and it is distinctly larger than the smallest human brain of the present day ; but it exhibits some pecuilarities that are more suggestive of the ape pattern than any other human brain hitherto studied. The whole skull, indeed, is curious, and must have belonged to a human creature very different from modern man. The lower jaw is comparatively weak, but it is so much elongated that it implies a relatively large face. Its retreating bony chin is shaped almost exactly like that of an ape ; it is much more ape-like than that of *Homo heidelbergensis*. The molar teeth, though essentially human, are unusually large and

elongated; and the much-enlarged canine tooth is so worn as to show that it completely interlocked with the upper canine, as in an ape. This canine tooth, however, differs in shape from that of any known ape, and agrees best with the temporary (or milk) canine of modern man. It is certainly a tooth of the permanent series, and therefore represents the first or preliminary stage in the making of a typical human dentition.

Piltdown man indeed belongs to the real dawn of the human race, and has been appropriately named *Eoanthropus*, or "dawn man." The original specimens, with fragments of a second skull and molar tooth discovered by Mr. Dawson in another locality near Piltdown, are now in the Geological Department of the British Museum (Natural History).

Neanderthal Man.

The earliest form of man in Europe who was intentionally buried in security after death, is now known by several more or less nearly complete skeletons from the caves and rock shelters of France and Belgium. The first skeleton, of which only the top of the skull and a few other fragments were rescued from destruction, was found in the Neanderthal (or valley of the Neander) near Düsseldorf in Germany. The best French skeletons were found with flint implements of the peculiar pattern which is met with in the cave of Le Moustier in the Dordogne. The race represented is therefore commonly known as that of Neanderthal or Mousterian man.

The finest skeleton of Neanderthal man, which was described by Prof. Marcellin Boule and is now in the National Museum of Natural History at Paris, was found in 1908 in a small cave near La Chapelle-aux-Saints in the Corrèze in south-west France. The circumstances showed that it had been intentionally buried, while the associated flint implements and remains of woolly rhinoceros, reindeer, hyæna, and other animals proved its geological age. A leg of a bison, which must have been covered with flesh when it was buried, seems to have been placed there as food for the deceased in a future life. The skull is relatively the largest ever seen in healthy man, and the brain-case, which is curiously depressed and expanded behind, is larger than that of the average modern European. The brain, however, may have been inferior in quality. There are strongly inflated bony brow-ridges, as in an ape; and the face also slightly approaches that of an ape in being relatively large and in having no depression in the bony cheek beneath the eye. The mouth is also very large, but the teeth are in all respects typically human, and the bony chin only differs from that of modern man in being sharply truncated, not prominent near the lower edge. The backbone is remarkably stout, about 2 inches shorter than usual, and the man must have

been of short stature. The arm is relatively long, and the two bones of the forearm are much arched, thus again retaining marked traces of an ape ancestry. The thigh bone is stouter and more bent than in ordinary man, and the shin bone is comparatively short and stout. While essentially human, therefore, Neanderthal man had probably a slouching rather than an upright gait, and his heavy face would give him a bestial aspect.

The Home of Modern Man.

We may, then, pause to remark that the earliest known fossil remains of man approach the hypothetical ape ancestor in at least two distinct ways. In one case there are no bony brow-ridges, but an ape-like jaw; in the other case, there are great bony brow-ridges, but a typically human jaw. So far as the scanty evidence goes, it fulfils our expectation of finding more than one kind of "missing link."

In Western Europe there is still no indication of typically modern man having lived with the immature grades of humanity just described. All statements to the contrary are based on modern burials which have been wrongly interpreted. In the metropolis of early man in central France, however, typically human skeletons are found in deposits in the rock shelters and caves which are immediately above those containing the remains or handiwork of Neanderthal man. As no skeletons of an intermediate race have been discovered, it may therefore be inferred that modern man originated elsewhere and appeared as an immigrant in this part of the world. Indeed all our present knowledge suggests that the successive phases of dawning humanity were passed through somewhere in the East, probably in South Central Asia. In that case, the periodical westward migration of peoples which is so familiar a feature of historic times must have begun in remote prehistoric antiquity.

One reason for suspecting that South Central Asia may have been the original home of man is that, just before his beginnings, a very varied assemblage of great apes lived in the forests of northern India. They are unfortunately known only from a few scattered teeth and fragments of jaws found in the deposits of Miocene age which now form the Siwalik Hills, so that we have very little information about them; but no such series of great apes has hitherto been discovered elsewhere. Now, at the beginning of the Miocene period, the Himalayan Mountains did not exist, and (as the late Joseph Barrell first suggested) it may have been during the uplift of this mountain range at the end of the period that primitive man came into being. As the land rose, the temperature would be lowered, and some of the apes which had previously lived in the warm forest would be trapped to the north of the raised area. As comparatively dry plains would there take

the place of forests, and as the apes could no longer migrate southwards, those that survived must have become adapted for living on the ground, and acquired carnivorous instead of frugivorous habits. By continued development of the brain and increase in bodily size, such ground apes would tend to become man.

THE NATIVES OF AUSTRALIA AND TASMANIA.

It has long been generally recognised that the lowest races of men in the present-day world are the blacks who inhabit Australia and those who, until lately, survived in Tasmania. They have often been regarded as closely related to the Neanderthal man who disappeared so long ago from Europe; but the discoveries of skeletons in France, already mentioned, show that the two races are entirely different. The remote lands of the southern hemisphere have always been the refuges in which old types of life have survived long after they became out-of-date and displaced in the more progressive northern hemisphere. There is, however, still no evidence of the Neanderthal or any earlier race in the south, and the Australians and Tasmanians are probably the survivors of the true men of later Pleistocene times. Their immediate ancestors seem to have had a much wider range in the southern hemisphere at a recent period, for an Australoid skull is known from a rock-shelter at Wadjak in Java, and another skull, associated with parts of the skeleton, which seems to have similar relationships, was found in 1921 buried in a cave in Northern Rhodesia. The Rhodesian skull, however, is unique in having the most inflated bony brow-ridges and the largest face ever seen in man. At first sight, these features seem more ape-like even than the corresponding parts of the European Neanderthal man; but more careful examination shows that the face is not enlarged on the ape model—the enlargement is not in the middle of the face, as in the ape, but round the edge—and the only known specimen which approaches the Rhodesian in the depth and extent of the bone below the nostril is a fossil Australian skull from Talgai in Queensland. In the characters of his brows and face, therefore, Rhodesian man probably exhibits merely a modern reversion to an ancient human type.

It may be added that man does not appear to have reached the American continent until much more recent times, for none of the fossil remains hitherto found in that region of the world differ essentially from the corresponding parts of the skeleton of the existing American Indians.

For further details, with illustrations and references to literature, see the English translation of M. Boule's "Les Hommes Fossiles" (1923); W. J. Sollas, "Ancient Hunters," third edition (1924); A. Keith, "The Antiquity of Man," second edition (1925); also "A Guide to the Fossil Remains of Man," published by the Trustees of the British Museum.

THE HUMAN BRAIN.

By Prof. GRAFTON ELLIOT SMITH, F.R.S.

The human brain is the instrument of the high powers of intelligence that distinguish man from all other living creatures. In animals endowed with the power of voluntary movement, which necessarily involves the ability to choose between conflicting impulses, the fundamental condition of progress is the attainment of quickness of appropriate response. The evolution of the nervous system is the means employed to enable increasingly complex and more completely adapted muscular actions to be performed with promptitude and precision.

Mammals differ from all other living creatures in having a true neopallium, a development of a region of the cortex of the brain in which sensory impulses from all parts of the body meet, react on each other, and directly influence the mechanism that initiates movements; this is an instrument of almost unlimited potentialities for the cultivation of skilled movements of increasing degrees of complexity and adaptation to diverse circumstances. In man these potentialities achieve their highest expression.

The human cerebral cortex provides the vital mechanism that can be fashioned by education to initiate and control an almost endless variety and complexity of muscular actions. It is able to perform these functions in virtue of the fullness of the information it obtains from a variety of sense-organs and the efficiency of the amazing machinery in the central nervous system for integrating the effects of these afferent currents and for controlling increasingly complex combinations of groups of muscles. But even more important is the ability of the neopallium, by some means which is quite unknown, to record the results of past experience and to put the influence of such knowledge at the service of the muscular system. This not only provides the means whereby behaviour can be modified in the light of knowledge, but also enables a high degree of automatism to be acquired

by training, which is perhaps the most essential factor in the attainment of high degrees of skill. The acquisition of these extensive powers plays a fundamental part in the development of the physiological dispositions which are expressed in intellectual operations. In the evolution of man the attainment of increasingly skilled movement involved the growth of mind.

Upon the lateral aspect of the cerebral hemisphere in most of the apes there is a furrow which was supposed to be so peculiarly distinctive of these Primates that it was labelled the *Affenspalte* or ape-fissure. More than twenty years ago its presence was demonstrated in the human brain, and as its own name was clearly inappropriate, the new designation, *sulcus lunatus*, in reference to the semi-lunar form it usually assumes, was given to it. The identification of this furrow was followed by the measurement of the extent of the *area striata*, the cortical area responsible for its presence, in which the optic radiations end; this led to the discovery that the visual receptive territory is just as extensive in the brains of many monkeys, even small macaques, as it is in those of men. The investigation showed the important part played by the early cultivation of vision as the dominant sense in man's ancestors, and pointed to the necessity for a detailed study of how and why this particular trend in evolution should have led to results of such vast significance as the emergence of the human mind.

Man has emerged as the result of the continuous exploitation, throughout the Tertiary period, of the vast possibilities which the reliance upon vision as the guiding sense created for a mammal that had not lost the plasticity of its hands by too early specialisation. Under the guidance of vision the hands were able to acquire skill in action, and incidentally to become the instruments of an increasingly sensitive tactile discrimination, which again reacted upon the motor mechanisms and made possible the attainment of yet higher degrees of muscular skill. But this in turn reacted upon the control of ocular movements and prepared the way for the acquisition of stereoscopic vision and a fuller understanding of the world and the nature of the things and activities in it. For the cultivation of manual dexterity was effected by means of the development of certain cortical mechanisms; and the facility in the performance of skilled movements once acquired was not a monopoly of the hands, but was at the service of all muscles. Skilful use of the hands was impossible without the appropriate posturing of the whole body. High co-ordination of hand movements and high co-ordination of movements localised elsewhere in the body must go together. The sudden extension of the range of conjugate movements of the eyes and the attainment of more precise and effective convergence were results that accrued from this fuller cultivation of muscular skill. They were brought about as the result of the expansion of the prefrontal cortex, which

provided the controlling instrument, and also by the building up in the midbrain of the mechanism for automatically regulating the complex co-ordinations necessary to move the two eyes in association in any direction.

The attainment of stereoscopic vision enormously enhanced the value of the information acquired by the eyes. The development of *maculæ luteæ* made possible the fuller appreciation of the details, the texture and the colour, of objects seen; and in association with the increased precision of muscular control, enabled the eyes to follow the outlines of objects and appreciate better their exact size, shape and position in space. But this completer vision of objects in the outside world stimulated a curiosity to examine and handle them, and so led to a yet further cultivation of skill in movement and an enhancement of tactile discrimination. This higher skill was attainable because the powers of stereoscopic vision conferred more accurate control on the hands than was possible before it was at their service.

Thus the fuller cultivation of the results of the visual powers provides a new stimulus and new means for enhancing vision itself, and this cycle of developmental changes was repeated again and again in the history of the Primates, at each stage leading to a further enhancement of muscular skill and visual acuity.

It is of fundamental importance to remember that one result of this continued handling of objects is the attainment of a fuller understanding of the nature of the objects seen and of the forces that are operating. The closer correlation of the information gained by vision and touch played a leading part in the cultivation of an appreciation of form, which represents the germ of the æsthetic sense. There also emerged the aptitudes to estimate weight and to discriminate between textures.

When these had attained such a degree of exactitude that it became possible for the individual to distinguish sharply one object from another and to appreciate its physical properties and understand something of its significance, the time had arrived when the process of naming it acquired a definite biological value. Man's ancestors were already provided with the muscular instruments for speech and the ability to use them for the emission of a variety of signals, mainly in the nature of cries to express emotional states. Hence, long before the need made itself felt for an instrument to express the names of objects, it was already in being; and all that required to be done was to devise the necessary vocal symbolism to express the visual experience—to give a name to an object seen. Moreover, long before the discovery of articulate speech, the ancestors of modern man were conveying information of an intellectual kind one to another through the visual appreciation of the meaning of gestures and facial expressions. With the introduction of an auditory symbolism, man became able to convey this information in a manner more precise and more capable of intellectual elaboration.

Thus the acquisition of speech was based primarily upon the fuller understanding of the world around the ancestors of men and the need for names as a sort of shorthand concisely to express the various attributes of a single object and other more complex states of consciousness; but it involved the seeing eye and the understanding ear and the highly skilled muscular act involved in phonation and articulation. In other words, while the expansion of most cortical areas is essential for the interpretation of experience, the special development of territories in the neighbourhood of the areas concerned with the reception of acoustic and visual impulses, and with the control of the musculature of the head and neck, should be expected.

If the brain of man's nearest relative, the gorilla, be compared with the human brain, it will be found that the enormous increase in the cortical territories of the latter affects chiefly three areas, the parietal region (especially that part of it known as the supramarginal and angular convolutions), the prefrontal region, and the inferior part of the temporal area. These areas are concerned respectively with the comprehension of speech, with muscular skill, and with speech, and are the areas that reach their full development last in the human child. They were the most defective parts of the brains the forms and proportions of which can be inferred from the moulds of the brain-cases of *Pithecanthropus* and *Eoanthropus.*

Appreciation of the nature of the objects and events happening in the outside world are dependent upon certain cortical developments which did not occur until man's immediate ancestors were assuming human qualities. The attainment of the realisation of space and time, and the faculty of recognising objects by their shape, colour, size, and texture, marked the transformation of the ape into a man. For the ability to appreciate these things made it useful for him to devise names for things, and so initiated the development and use of language, with all that language implies in vastly increased capacity for thinking in symbols of value to himself and intelligible to others.

When man began to examine the objects around him, he did not neglect the study of himself. The knowledge he accumulated of the world included a knowledge of his own body and the estimation of the æsthetic qualities of his fellows, for vision came to acquire an increasing influence in his selection of sexual mates; and it is possible that in the human family, Darwin's claim for sexual selection may find much ampler confirmation than most biologists are inclined to attach to it for other organisms. No one can question the appeal of physical beauty to mankind, and it is difficult to believe that an attraction so universal and deep-seated could possibly have been devoid of effect in the process of transmuting the uncouth form of an ape into the graceful figure of a human being.

THE CIRCULATION OF THE BLOOD.

By Prof. E. H. STARLING, F.R.S.

Before Harvey's time, anatomists, by dissection of the bodies of man and animals, had shown that the heart in the chest is connected by tubes to all parts of the body, and they had described the structure of the heart. Although it was known that these tubes and the heart contained blood, which in the living body was in motion, no clear idea was held as to the function of the heart until the demonstration by William Harvey in 1616 that the blood was in continual circulation throughout the body, the circulation being maintained by contractions of the muscular wall of the heart.

The heart is a hollow organ which presents four cavities—two thin-walled, the auricles, and two thick-walled, the ventricles. There is no communication in the heart itself between the right and left sides. The orifices between the auricles and ventricles are provided with valves which allow the blood to pass only from auricles to ventricles. From the ventricles also lead off two large tubes, the pulmonary artery from the right ventricle, and the aorta from the left ventricle. The orifices of these two tubes (arteries) are provided with very perfect valves, which prevent the regurgitation of blood from the arteries into the heart, but present no resistance to the flow of blood from the heart into the arteries. The heart can be considered as a hollow muscle. When the muscle contracts all the cavities of the heart become smaller, so that the contents of the ventricles are forced through the valves into the arteries.

The circulation is really a double one, and could be maintained if the right and left sides of the heart were separated into two distinct organs. From the left ventricle the blood passes through the aorta and then by large arteries to all the tissues of the body, where it flows through fine hair-like vessels, the capillaries, which permit the passage of material through their walls and so allow the tissues of the body to take up oxygen and food from the blood.

The capillaries of the tissues lead into thin-walled tubes, the veins; and these gradually run together until they form two large veins called the superior and the inferior venæ cavæ, which enter the right auricle. The blood going to the tissues is bright red in colour (arterial blood); that coming from the tissues has lost a large part of its oxygen and is bluish in colour (venous blood). From the right auricle the blood passes into the right ventricle, and when this contracts is forced into the pulmonary artery and through the capillaries of the lungs. These capillary vessels form a fine-meshed network, which surrounds all the air vesicles, and are separated from the air in these vesicles only by a microscopic layer of cells. The blood therefore loses the carbonic acid collected in the tissues, which is the result of tissue activity, and takes up oxygen from the air, so that it leaves the vesicles bright red in colour, being once more arterial blood. From the lung capillaries the blood is collected into four thin-walled tubes, the pulmonary veins, which enter the left auricle, and passes from the left auricle into the left ventricle, to recommence its circuit through the body when the ventricle contracts.

In order that a town may be supplied with water for its domestic purposes, it is necessary to maintain a head of pressure in the water mains. In the same way, it is necessary to maintain a pressure in the large arteries, in order that blood may be supplied to the different tissues according to their needs. The arterial blood pressure was first mentioned by the Rev. Stephen Hales, who was also the first to point out its importance. In man, we find that in the large arteries the blood pressure varies at each heart-beat between 80 and 120 millimetres of mercury—*i.e.*, we have a head of pressure of about one-seventh of an atmosphere.

In order to maintain this pressure there must be a resistance to the free outflow of blood from the great arteries, and to this end the muscular walls of the arterioles are kept by the central nervous system in a constant state of partial contraction, so that they only allow the escape of blood with difficulty. The arterial blood pressure, on which the circulation to the tissues depends, is therefore determined by two factors—(1) the amount of blood pumped out into the arteries, and (2) the resistance to the escape of blood afforded by the contraction of the small arterioles. With this head of pressure in the arteries, the central nervous system, the master tissue of the body, can always receive a sufficient supply of blood with its contained oxygen. If by any means there is a diminution of the arterial pressure, the central nervous system at once takes measures to raise the pressure again by constricting the arterioles of all other parts of the body, so as to maintain the blood pressure and therewith the circulation through the brain.

The central nervous system controls not only the condition of the arterioles, but also the rate and force of contraction of the muscle which forms the heart pump. Thus the heart may be

quickened or slowed as the result of emotions. In the same way, the blood vessels may be constricted or dilated—the pallor or flushing produced by different emotions is familiar to everyone. The brain may also affect the circulation indirectly. One of the main factors in increasing the return of blood to the heart is the contraction of the voluntary muscles, which press on the blood in the veins and send it on towards the heart. In this way, by increasing the inflow into the heart, muscular exercise increases the output from the heart, and therefore tends to cause a rise of blood pressure; the increased inflow of blood may also reflexly affect the heart centres and cause a quickening of the pulse.

It is important to note that the rhythmic contraction of the heart, which continues from the formation of the heart in the developing child until the death of the individual, is dependent on the heart itself. The heart of a cold-blooded animal cut out of the body will beat for hours or even days. The heart of the warm-blooded animal, if supplied with oxygenated blood, can be made to beat for many hours after being cut out of the body.

MUSCULAR WORK.

The Mechanism.

By Prof. A. V. Hill, F.R.S.

Bodily movement is an apparently simple phenomenon and its characteristics can be measured in absolute physical units. For example, the work done by a contracting muscle can be measured in ergs and as accurately as the work done by a steam engine. The mystery of how the muscle fibre performs its important and easily recognised function has long appealed to those who desired to study living response in a form approachable by the methods of exact science. Moreover, there was the hope that once a beginning had been made, the results and generalisation attained by studying muscle might be found to apply to all other forms of living tissue, and so a way be found of bridging the gap between biology and physics.

The subject is full of great names, Helmholtz, Fick, Blix, and many others. Of British workers, Gaskell's and Mines' researches on the isolated heart have proved the fundamental basis of modern cardiology. W. M. Fletcher perceived the extreme importance of the fact that oxygen delays the onset of, or abolishes, fatigue in an isolated muscle; W. M. Fletcher and F. G. Hopkins, working together, recognised that lactic acid was the key to this phenomenon and that the concentration of it in a muscle is high in states such as fatigue and *rigor mortis*. From these original sources has arisen a network of investigations, illuminating many branches of physiology and throwing sidelights on several aspects of medicine and everyday life.

When a muscle contracts, lactic acid is liberated, in amount proportional to the strength of the contraction: when it relaxes lactic acid is neutralised: while the contraction is upheld, a balance is maintained between continual production and continual neutralisation. During the succeeding ten minutes, restoration occurs: the lactic acid is slowly removed in the "recovery

mechanism" of the muscle, but only if oxygen be present; it is restored to its previous state, the necessary energy being provided by the oxidation of a fraction of the lactic acid. The system is analogous to an electrical accumulator, together with a motor and a dynamo; the accumulator can rapidly provide mechanical work when needed, but must be slowly recharged afterwards by the use of energy required to drive the dynamo. Oxygen in muscle is used only in recovery from previous exertion, even during exercise, each element of the oxygen consumption is used in recovery from a previous element of effort.

The lactic acid arises from and is restored to glycogen, a body peculiarly important in connexion with modern work on carbohydrate metabolism, insulin and diabetes; indeed, the fact that, in muscle, glycogen breaks down into lactic acid more readily than does glucose, suggests that a study of the chemical nature of glycogen, and its reactions in the muscle mechanism, may find some strange and interesting application to the problems of human diabetes.

The onset of fatigue is due to the accumulation of lactic acid in the muscle: the limits of violent effort are set by the maximum amount of acid which the body can tolerate. During exercise, and in the earlier stages of recovery, the acid passes into the blood; part of its oxidative removal may even occur in distant portions of the body. The laboured respiration accompanying, and following, active exertion is due to acid in the bloodstream, affecting the respiratory centre in the brain. The laboured respiration occurring even after moderate exercise, in some forms of cardiac or other disease, is due to acid appearing in the blood as the result of an imperfect mechanism for its oxidative removal. The changes occurring in the blood, as the result of exercise or of oxygen want, in respect of its combinations with oxygen and carbon dioxide, are partly due to lactic acid.

It would seem a far cry from the obscure labours of physiologists to the making of records on the athletic track. Yet a study of the oxygen intake and the carbon dioxide output in man, during and after violent exertion, together with the results of recent work on the dynamics, thermodynamics and chemistry of isolated muscle, have shown otherwise. A man's capacity for muscular effort is limited by precise and clearly defined factors, depending upon his supply and utilisation of oxygen, his economy in movement, his efficiency in recovery, and the maximum amount of lactic acid to which his body will submit. The general type of relation existing between the distance (in a flat race) and the speed at which it can be run, can be predicted on simple physiological grounds. It has been the writer's good fortune, though himself an inconsiderable performer, to have had for many years a close personal acquaintance with athletes, and it has been recently almost a daily pleasure and excitement to find some phenomenon.

known to runners, turning up again in another form in the physiological laboratory. Mountaineers, airmen, students of human movement in industry and everyday life, will find the same.

We must recall, however, that it was the pure science which found the path and built the bridge, and we are really only at the beginning of our knowledge of muscle. The adventurer's instinct is still needed: it is necessary to explore as well as to exploit.

The recovery process, capable of completion only in the presence of oxygen, still goes on in part, even in its absence: the details of the process are unknown. The course and magnitude of the liberation of energy associated with all phases of contraction and recovery have been described, and it remains for the chemist to fit his details into the thermodynamic picture. Again, there are many curious and complex effects connected with the actual shortening process itself: changes in energy liberated, changes in work done, changes in mechanical efficiency. There are the physico-chemical factors underlying the power a muscle possesses of using oxygen: there are the highly specific actions of certain drugs upon its mechanism. But behind them all remains the mystery the solution of which—still so far away—offers so fruitful a field of understanding men's bodies; the mystery of the little fibre, about $\frac{1}{500}$ of an inch thick, designed and constructed in a material not unlike egg-white, growing, feeding, repairing itself, and exhibiting in its function so admirable a simplicity, an efficiency, and a directness of apparent purpose.

The Energy of Expenditure.

By Prof. E. P. Cathcart, F.R.S.

Although man is no machine in the ordinary sense of the term, he, just like the locomotive, must be supplied with fuel for the production of work. In the case of the locomotive, however, the fuel is only required for the performance of work, whereas in the case of man the fuel—food—not only supplies the necessary energy for the performance of work, but it also serves for the repair of the wear and tear of the tissues and for growth. Before a correct assessment can be made of the amount of food required, it is necessary to determine the amount of energy expended.

This question of the best and most accurate method for the determination of the energy expended is no new one. The first experiments, which changed the whole outlook on the problem, were made almost at the same time, about 1780, by Crawford in Glasgow and Lavoisier in Paris. Crawford, indeed, claimed priority, but his insight into the problem was not so fundamental as that of his French rival. The method then adopted is in essentials the one we use to-day. It consists in the estimation, either directly

or indirectly, of the amount of *heat* lost. The thermal unit or calorie is chosen because eventually all the potential energy of the food consumed or the tissues oxidised is reduced to heat, and, further, the external work done can also be measured in heat units. Thus by the use of the calorie we obtain a common factor for the statement of energy problems. The calorie used to-day by physiologists throughout the world is the large or kilo calorie which represents the amount of heat required to raise the temperature of one kilogram of water through 1 degree Centigrade. The amount of external work done is calculated in kilogram-metres—*i.e.*, the amount of energy expended in raising one kilogram vertically through one metre distance. Largely from the pioneer work of Joule, of Manchester, we know that approximately 427 kilogram-metres equal one large calorie.

The amount of energy, calculated as calories, contained in the food consumed is determined by burning a weighed amount of the food material, under very definite conditions, in an apparatus called a bomb calorimeter, and measuring the amount of heat liberated. A great many of the earlier determinations of the calorie values of foods were made by Frankland, of Birmingham, in 1866.

The estimation of the energy lost by the living organism or man may be carried out either directly or indirectly. In the direct method, which was the one originally adopted, the amount of heat given off by an animal was measured by noting the increase in temperature of the cold water or ice which surrounded the chamber in which the animal was placed. The modern development of this method has been for the most part confined to America, and is associated with the names of Atwater, Rosa, Benedict and Lusk.

The indirect method, which is much easier and less expensive, has been developed chiefly in Britain and in Germany. Although a somewhat similar method was adopted by Smith, in London, so long ago as 1859, Zuntz, of Berlin, was the first to devise a trustworthy and portable apparatus, but it had the drawback of being heavy and cumbrous. The method introduced by J. S. Haldane and C. Gordon Douglas, of Oxford, is infinitely better, being both accurate and easy to use. In this indirect method, the changes in the composition of the inspired and expired air are measured. The subject, with his nose " clipped," breathes through a special mouthpiece (or a special facepiece) equipped with two one-way valves, an inspiratory and an expiratory. The mouthpiece on the expiratory side connects by means of rubber tubing with an airtight bag which serves to collect *all* the expired air for the period of the experiment. The amount of air expired is measured by passing it through a meter and a sample of this air is taken for analysis.

The analysis shows, as compared with the composition of the normal inspired atmospheric air, an increase in the content of

carbon dioxide and a diminution in the amount of oxygen. The alteration is due to the combustion of the various foodstuffs in the tissues. The amount of oxygen used is multiplied by a factor, which is obtained from the ratio of the amount of carbon dioxide breathed out to the amount of oxygen utilised, and the result is a statement of the energy expended in calories. The assumption is made that the amount of oxygen utilised is a direct index of the amount of material burnt in the tissues. That this assumption is correct is shown by the fact that from a series of double estimations made by the direct and indirect methods, the two varied in their final result by less than 1 per cent.

As the apparatus can be utilised for the determination of the energy expenditure of mobile subjects, it is possible to examine and compare the energy expended by a great variety of workers. It is possible to assess and compare the cost of work, for example, of such very diverse occupations as postmen, riveters, tailors, clerks, etc.

If, however, it is desired to study more particularly the various phases of energy expenditure, it is customary to make the subjects perform given amounts of work on special types of apparatus known as ergometers (work-measuring machines). These machines are of different types; some are used for the investigation of work performed by the arms either of rotary or lever movement, whereas others have been devised, such as the "walking" platform and the bicycle ergometer, for the study of the cost of movement of the leg muscles. As a general rule, the work done consists in rotating a wheel against resistance which can be varied within wide limits. Under these conditions, it is possible to carry out very accurate determinations of the actual amount of work a man can perform in the course of an hour, or eight hours, or any other given unit of time.

A number of investigations have been made of the energy expenditure in various occupations by this method of indirect calorimetry, but a great deal of work must yet be done before anything like final conclusions can be drawn regarding the average energy expenditure of any class of workers. In spite of the importance of this subject, which is in reality the basis for the study of the nutrition of man, Britain possesses no institute or laboratory specifically devoted to the study of the nutrition of man, although it has at least two institutes for the study of the nutrition of farm animals.

THE BIOLOGICAL ACTION OF LIGHT.

By Prof. D. T. Harris.

The distribution of solar energy over the British Empire shows immensely wide variations, and inhabitants of the large cities of Britain probably receive the smallest share. It is only in recent years that the London child sufferer from tubercular joint disease has had the chance to enjoy sun baths. The pioneer work of Sir Henry Gauvain at Alton and Hayling Island has demonstrated conclusively the curative action of the sun's rays in bone and joint disease of tubercular origin. The wonderful results of Dr. Rollier in Leysin, in the Swiss Alps, show on a more extensive scale the beneficial effects of insolation at high altitudes. To Dr. C. W. Saleeby is due the credit for bringing this powerful agent to the notice of the English-speaking public. It was through his untiring efforts that the Medical Research Council appointed a committee to investigate the biological action of light, under the chairmanship of the late Sir William Bayliss, who was the first to write an authoritative account of this youthful and difficult subject ("Principles of General Physiology," Longmans).

The investigation of the mode of action of an agent like light, to which we and our ancestors through the ages have grown so accustomed, presents unusual difficulties; we are apt to accept it as an unanalysable fact. No one will question the existence of the stimulating effect of the morning sun, but to determine the tissue on which it acts and its mode of action, whether chemical or electrical, is a problem demanding the co-operation of physiology, chemistry and physics.

The physicist continues to make his valuable contributions. The colours of the rainbow, which represent the visible part of the spectrum, are now known to be only a very short link in a huge electromagnetic spectrum connecting the immense waves of

wireless telegraphy, on one hand, with the extremely small X-ray waves, on the other. All these waves travel at about the same speed, eight times round the earth in one second. On the red side of the visible spectrum we pass into the region of dark heat rays, including those emitted from a hot flat iron. These, though invisible, can be appreciated by the heat receptors in the skin of the cheek. Dark-heat, or infra-red rays, constitute about half the energy we receive from the sun. On the more active violet side of the visible spectrum the waves are only half the length of the red waves, and as we pass beyond the faintly visible violet we come to a chemically active region called the ultra-violet, where the waves average only half the length of the violet. These ultra-violet rays are proportionally few in ordinary daylight; they are absorbed by window glass, and so cannot enter a house with closed windows. They are also reduced in intensity by absorption in the atmosphere, and hence are more abundant at high altitudes, as in the Alps.

It has been supposed that man through the long ages has become immune to the visible rays of the sun. It is only when the infra-red rays become excessive that he seeks the shade, and in this way he also escapes from the destructive action of a too powerful dose of ultra-violet light. It is the infra-red which are the potent rays in the causation of sunstroke, whilst the ultra-violet cause sunburn. The latter may be easily demonstrated by exposing an area of skin for five minutes to the ultra-violet light obtained from an artificial source rich in ultra-violet rays—*e.g.*, the mercury vapour lamp in a quartz tube; the other rays can be filtered off, the heat rays by a water cell and visible rays by a cobalt-quartz plate.

This powerful action on the human skin is of great interest. After the sunburn subsides the majority of people develop pigment. If now the same region of skin be exposed to ultra-violet light, it will be found that a burn does not appear on the pigmented skin, but only on the neighbouring unpigmented skin; protection has therefore been conferred by the development of pigment. This experiment suggests the mode of evolution of the pigmented races of the tropics. How the pigment actually works, especially in view of the fact that a black body is a better absorber of heat than a white body, is a problem under investigation.

Another effect of ultra-violet light and one which has been definitely proved is its destructive action on bacteria, and this has been applied commercially to the sterilisation of water by passing the water in thin sheets over quartz cylinders in which are placed large mercury vapour lamps.

Ultra-violet light appears to play a very important part in the growth and development of the young child, and may prove to be one of the chief agents in the prevention of the bony deform-

ities known as rickets. The results of some experiments seem to point to the conclusion that ultra-violet acting alone is a more powerful agent than when acting in the presence of the visible light. Indeed, the writer found that the stimulant action of ultra-violet light on the total chemical changes in the body could be annulled by the addition of visible light; a similar antagonising action of the visible light was found on the tonic effect of ultra-violet on the isolated stomach kept alive with oxygenated Ringer's fluid.

As only a short comparatively unexplored region exists between ultra-violet radiation and X-rays in the electro-magnetic spectrum, it is probable that many of the problems of the biological action of these two types of radiation may be solved simultaneously. Two outstanding differences, however, exist between them. The ultra-violet rays produce their effect in a few minutes, and their direct action is entirely superficial, while X-radiation sometimes takes weeks to reveal its effects, and it penetrates deeply into the tissues and is only stopped by dense structures like bone. The rays from radium produce effects on the tissues very similar to those of X-rays.

May we hope that the investigation of these artificial radiations in the laboratory will yield the secrets of the beneficial action of sunlight, and that man's activities will be directed to the removal from our atmosphere of the suspended matter which at present cuts off the health-promoting (ultra-violet ?) rays. It is a matter for some regret that the Empire on which the sun never sets has not developed great institutes for the open-air treatment with sun baths of the young victims of the darkness of our large cities.

THE ORIGIN OF THE SEED-PLANTS.

By Dr. D. H. Scott, F.R.S.

The seed-plants are, and (as geological history shows) have long been, the dominant sub-kingdom of the plant world. They include all Phanerogams, the Gymnosperms (such as Conifers and Cycads), as well as the true flowering plants or Angiosperms. These two divisions are widely different, both in their characters and in their geological record. The Angiosperms, in fact, are the youngest, while the Gymnosperms are among the oldest of the groups which constitute the vegetation of the land.

The Angiosperms alone (among living plants) bear "flowers" in the natural and usual sense of the word; they have their seeds enclosed in an ovary or seed-vessel, and are fertilised through the mediation of a stigma and conducting tissue. The Gymnosperms, as their name implies, have naked seeds, commonly borne on a cone; the ovule, or young seed, is fertilised directly, itself receiving the pollen, without the intervention of any accessory organs. It would take too long to enter into the further fundamental distinctions which render the two classes so profoundly diverse.

In the present article we are only concerned with the history of the older seed-plants, the Gymnosperms. The relation between them and the Angiosperms is another story, which we shall not touch on here.

Reproduction in Seed- and Spore-Plants.

All seed-plants alike are reproduced (apart from mere vegetative propagation) by means of complex bodies, the seeds, often of large size, always composed of various tissues, and usually containing an embryo. The spore-plants or Cryptogams, on the other hand, have extremely simple reproductive bodies, the spores, always minute, and usually consisting of a single cell. A fern,

such as the bracken, is a good representative of the higher spore-plants. Here all the spores are of one kind. When sown, the germinating spore gives rise, not to a fern, but to an independent little organism, the prothallus, on which the sexual organs are borne. Fertilisation is accomplished, in the presence of sufficient water, by the actively-moving male cells (spermatozoids) and the fertilised egg grows up into a new fern-plant, which produces spores, and so the cycle is completed.

This is a simple example. If we take a more advanced Vascular Cryptogam, such as a water-fern or a *Selaginella*, we find that sexual differentiation begins to show itself in the spores themselves, which are of two kinds, microspores and megaspores. The little spores, on germination, produce the free-swimming spermatozoids, and that is all; there is no prothallus worth mentioning. The large spores, on the other hand, develop a fairly massive prothallus (though it remains mostly enclosed within the megaspore-wall); this prothallus bears the female organs and ultimately serves to nourish the growing embryo.

Now this "heterosporous" condition, only met with in the highest spore-plants, is no doubt to some extent an approach towards the reproductive methods of the seed-plants, especially the Gymnosperms. The pollen-grains are clearly the same thing as the microspores. The female prothallus (endosperm) of a fir tree or a Cycad is quite comparable to that of a water-fern or *Selaginella*. The great difference is that in the seed-plant the megaspore (embryo-sac) is permanently retained within the sporangium, while the latter becomes enveloped by a new organ, the highly developed integument, or testa, constituting the seed-coat. The pollen (microspores) is received, and usually fertilisation is effected, while the ovule or young seed is still borne on the parent plant; as a rule the seed is not shed until the embryo within it is well developed.

It is evident, from what has been said, that a certain relation in the reproductive processes between the seed-plants and the highest spore-plants can be traced. Botanists, since these relations were first established by Hofmeister in the middle of the last century, have come to believe that the Gymnosperms (and ultimately the seed-plants generally) were descended from heterosporous Vascular Cryptogams. Opinion, however, has been much divided as to the special group or groups which played the rôle of ancestors. While the general relations seem clear, there is no sign, among living plants, of any transition from spore-plants to seed-plants beyond the one important fact that in the Cycads and the Maidenhair tree, fertilisation is still carried out in the Cryptogamic manner, by means of active spermatozoids.

EVIDENCE FROM EXTINCT PLANTS.

The question thus arises, what light does our knowledge of extinct plants throw on the problem of the origin of the

Spermophytes ? Palæobotanists, like other botanists, have held very diverse views, but for the last twenty years there has been a strong tendency to trace a connexion between the seed-plants and the ferns, through a group of Palæozoic seed-bearing plants, with a fern-like habit.

The existence of such a group was first realized in the year 1903. Up to that time it was commonly estimated that almost exactly half the species of known Carboniferous plants were ferns. Everyone knows of the fine "fern fronds" preserved as impressions in the coal measures. Most botanists never doubted that these familiar fossils were really the relics of true ferns. Sir Joseph Hooker, in 1848, expressed his conviction that the Carboniferous genus *Pecopteris* was "the fossil representative, if not congener, of the modern *Pteris* (bracken). It is not improbable that there are other genera of living ferns fossilised in the shales of the coal formation."

Doubts, however, began to arise so early as 1883, when the Austrian palæobotanist, Stur, pointed out that a considerable number of the Carboniferous fronds had never been found with fern-fructifications, and therefore, could not have been ferns. Stur's scepticism, though well justified, did little to shake the belief of palæobotanists in general.

From the anatomical side, evidence soon began to accumulate showing that some of the fern-like plants of the coal period could scarcely have been ferns in the strict sense of the word. Williamson first showed that in two genera with the foliage of *Sphenopteris* (quite like a fern), the structure in certain points approached that of a Cycad. He fully realised the significance of his discovery. In other genera also it was soon found that the foliage of ferns co-existed with certain anatomical characters of Gymnosperms.

In 1897 the German botanist, Potonié, suggested the foundation of a group, Cycadofilices, to embrace such intermediate or indeterminate forms, and his proposal found wide acceptance. So far, however, all was still in doubt, for we could not be certain whether these Cycad-ferns were seed-bearing plants or only Cryptogamic ferns simulating the structure of a higher class.

Discovery of Seed-Ferns.

The first definite evidence came from Prof. F. W. Oliver, who in 1903 identified the seed of *Lyginopteris oldhamia,* one of the plants in which Williamson had demonstrated a Cycad-like anatomy. Oliver found that the seed *Lagenostoma lomaxi,* already known to Williamson, bore on its husk or cupule peculiar glands, identical with those on the stem and leaf of the *Lyginopteris* with which the seeds were associated, but unknown in any other fossil plant. The internal structure showed further points of agreement, and the evidence, though indirect, has been generally

accepted as conclusive. It was further confirmed by the subsequent discovery of very similar seeds borne on branched stalks resembling the naked rachis of a *Sphenopteris* frond.

The seeds in question are highly organised and show important points of agreement with those of living Gymnosperms of the Cycad family. As the result of Oliver's discovery, the name "Pteridosperms" was coined, to apply to those Cycadofilices in which there was evidence for reproduction by seeds.

More obvious proof of the existence of "seed-ferns" was soon forthcoming. Dr. Kidston at once stepped into the field, and in 1904 showed us great seeds, of the size of a filbert, borne on fronds with the well-known leaflets of *Neuropteris heterophylla*. Then America made her contribution, for in the same year, Dr. David White, of Washington, proved that the maidenhair-like fronds of *Aneimites fertilis* and other species, of Millstone Grit age, bore among their leaflets numbers of little winged seeds. Then, a year later, the distinguished French palæobotanist, Grand'Eury, discovered fronds of *Pecopteris pluckeneti* studded all over with hundreds of seeds, winged like those of the *Aneimites*. This was the most startling revelation of all, for up to that time nobody had doubted that such species of *Pecopteris* were true ferns. Other cases of actual continuity between seed and frond have since been recorded; there is further a considerable amount of indirect evidence, from intimate and exclusive association, indicating that the seed habit was widely spread among the so-called Carboniferous ferns. In fact, it is now generally recognised that an actual majority of these fern-like plants were not true ferns at all, but Pteridosperms.

In all known cases it appears that the seeds of the Pteridosperms were borne on the frond itself, either on unaltered parts, showing the vegetative leaflets, or on special pinnæ reduced to a more or less denuded rachis. The occurrence of seeds on an ordinary leaf, otherwise little or not at all modified, is without direct parallel among living plants. The nearest analogy is to be found in the female *Cycas*, where the seeds are borne on leaf-like carpels which grow out from the main stem, just as the leaves themselves do. In the way the seeds were borne, the Pteridosperms appear to have been the simplest seed-plants known, though the seeds themselves were very far from simple.

Significance of Seed-Ferns.

The discovery of the existence in Palæozoic times of an extensive class of seed-bearing plants, in some respects primitive and externally altogether similar to ferns, naturally had a great influence on evolutionary speculation. It was thought by some botanists that we had at last tracked down the actual Cryptogamic stock from which the seed-plants were descended. The

Pteridosperms weredescribed as "Ferns which had become Spermophytes." The present writer at one time maintained that the fern phylum had been the source from which the great majority, if not the whole, of the seed-plants was derived. The Pteridosperms were regarded as the most primitive and the most ancient of the Spermophytes, and through them the Phanerogams generally were traced back to the fern stock.

Some botanists, however, were more cautious. The gravest warning came from Dr. Kidston, who wrote, in 1906: "The Cycadofilices [Pteridosperms] are undoubtedly the oldest group of 'fern-like' plants of which we have fossil evidence. . . . It seems therefore to be highly improbable that the Cycadofilices could have descended from plants to which the name 'fern' as understood in recent botany could be applied. What the progenitors of the Cycadofilices were, for the present remains unknown." Dr. Kidston's words, as it now appears, put the question in its true light. But for many botanists the temptation to hail a great phylogenetic discovery was too strong. The belief in the fern ancestry of the Pteridosperms, and through them of the other seed-plants, undoubtedly became prevalent.

There was much excuse for this idea. Attractive in itself, as offering a solution of one of the greatest problems of plant-evolution, it further seemed very natural in the light of our new knowledge. We had been accustomed to believe that half the Carboniferous plants were ferns. Then we had discovered that many, probably most, of these "Carboniferous ferns" bore seeds. They were "ferns which had become Spermophytes." Yet surely they were ferns after all—they were so like them. We should have reflected, with Brutus, "That every like is not the same."

Supposed Relationship with Living Ferns.

Let us look a little more closely into this likeness between ferns and "seed-ferns." Th resemblance in habit is undoubtedly striking in the highest degree. But it goes too far. An agreement so exact as to have led a botanist like Sir Joseph Hooker to refer to the bracken genus a plant now known to have been a Pteridosperm (*Alethopteris decurrens*, named *Pecopteris heterophylla* in Hooker's time) must indicate a very near relationship, if it can be trusted to prove any relationship at all. Yet there cannot, from the nature of the case, be any *near* affinity, for the Pteridosperms bore highly organised seeds, rivalling the most complex seeds of later times, while the ferns are spore-plants, pure and simple. Thus there is in any case such a tremendous gap that similarity of habit ceases to be any evidence of affinity.

That habit is illusory as a guide to relationship is a fact familar to all botanists. We need only recall such obvious examples as the resemblance between a Cactus and a succulent *Euphorbia*,

between a horsetail, a *Casuarina* and an *Ephedra*, or between a water-lily and a frogbit. The external likeness between ferns and Pteridosperms may be no more significant. The Carboniferous flora grew under peculiar conditions, and it may well be that similarity of habit among plants of that period is simply the expression of a like reaction to a special environment. The fern-habit, now for the most part restricted to one group of Cryptogamic plants, was in those days much more generally found appropriate to the prevailing conditions.

The theory of a direct relationship between ferns and "seed-ferns" has further been supported by arguments drawn from the anatomical structure. Various analogies have been traced between the structure of certain Pteridosperms and that of some recent ferns. Such comparisons are fallacious, for it is inconceivable that Cryptogamic ferns now living should show any demonstrable affinity with a long-extinct race of Palæozoic seed-plants. The resemblances which have been found are no doubt analogies and nothing more.

Seed-Ferns and their Contemporary True Ferns.

The only sound structural evidence must clearly be sought from the comparison of "seed-ferns" with their contemporaries among the true ferns of Palæozoic age. Such a comparison proves to be by no means favourable to the hypothesis of a direct connexion. Some of the "seed-ferns" have a very simple anatomy, and so have some of the true ferns of the same period. But the simplest representatives of the two groups are not in the least like each other. Further, if we compare the more complex forms, we find that anatomical advance in the ferns and their seed-bearing contemporaries followed very different lines. Neither do we meet with any approximation in structure between the two, if we trace back both groups to older rocks, such as the Lower Carboniferous.

We still have but little detailed knowledge of the pollen-bearing organs of the Pteridosperms. It is often extremely difficult to distinguish between the pollen-sac of a seed-plant and the asexual sporangium of one of the higher spore-plants. Where, as in the Pteridosperms, the pollen-sacs were borne on the frond and not on a specialised sporophyll (stamen) the distinction may almost disappear. We are scarcely yet in a position to compare the true ferns with the "seed-ferns" in this respect. It may, however, be pointed out that in the one case in which the pollen-sacs of an undoubted Pteridosperm are adequately known (*Crossotheca höninghausi*, the male fructification referred to *Lyginopteris*), Dr. Kidston found that they were bilocular, a condition not met with among the sporangia of the ferns.

When we come to the seeds, all resemblance to or even analogy with the reproductive organs of true ferns vanishes. Broadly

speaking, the seeds of the Pteridosperms, many of which have been most thoroughly investigated, were on the highest level of complexity; they show no closer relation to a fern-sporangium than does the seed of a living Cycad or the Maidenhair tree. In fact, it would scarcely be too much to say that, in the Pteridosperms and other Carboniferous Spermophytes, the seed reached its zenith of elaboration, later changes having been largely in the direction of simplification; only a few living plants, chiefly those just mentioned, have retained the old complex Palæozoic type of seed.

True Ferns and Seed-Ferns are Distinct Lines.

While we believed that the Pteridosperms had once been ferns, we were under the necessity of deriving their seeds from Cryptogamic spore-sacs, such as ferns possess. Many ingenious hypotheses were framed in order to explain how so profound a transformation might have been effected. But they remained hypotheses and nothing more. No basis of fact could be found, for nothing in the least suggesting an intermediate stage is known. It would be difficult to produce any vegetable object less like a fern-sporangium than many of the seeds referred to Pteridosperms.

On the whole of the evidence, one must conclude that there are no sufficient grounds for deriving the so-called "seed-ferns" from the true ferns. The two phyla appear to have run on independent and parallel lines. Possibly they may ultimately be found to converge, if we can ever trace them back far enough, in some common initial group of primitive land-plants. The true inference from the mixed characters of the Pteridosperms would seem to be, not that the seed plants are descended from ferns, but that they, or at least some of them, once passed through a fern-like phase, just as some of the Euphorbias are now passing through a cactus-like phase.

Representatives of the Seed-Plants in the Geological Ages.

Once more, therefore, we are left without any satisfactory theory of the origin of the Spermophyta. We may, however, briefly recall what is known of their early history, in order to see more clearly how the matter stands. In Upper Carboniferous times, besides the Pteridosperms, there was the great Cordaitean family of fine forest trees, with tall branched trunks, long simple leaves, and complex male and female cones or catkins. The seeds, like those of the Pteridosperms, were of the Cycad type. The Cordaiteans, while totally different from the "seed-ferns" in habit, show certain points in common with them, notably in the organisation of the seeds, and also in some anatomical details.

When we go back to the Lower Carboniferous, we find little trace of the Cordaiteans, but another family of great trees was flourishing. The well-known fossil trunk set up in the garden of the British Museum (Natural History) belongs to one of them, the Craigleith tree, *Pitys withami*. The *Pitys* trees had in some respects a peculiar anatomical structure: their foliage, as Dr. Gordon has recently shown, consisted of small simple leaves, something like stout pine-needles, but more complex in internal structure. It was thus quite different from the leafage either of the Cordaiteans or the Pteridosperms. Dr. Gordon thinks he can trace some affinity between *Pitys* and the puzzle-monkeys (Araucarians) among recent Conifers. Unfortunately, nothing is yet known of the fructification, but the whole vegetative organisation is that of advanced Gymnosperms. Thus, in Lower Carboniferous times, the seed-plants were represented by at least two perfectly distinct groups, the fern-like Pteridosperms and the Araucaria-like *Pitys* family.

Descending from the Carboniferous to the Upper Devonian we have found, until lately, little evidence of the presence of Pteridosperms. Quite recently, however, it has been announced from America that a whole forest of Pteridospermous trees, of Upper Devonian age, existed at Gilboa, in the State of New York. The remains of the forest have long been known, but it is only within the last year or so that the seeds borne on the fern-like fronds have been recognised. Further details of this striking discovery will be awaited with interest. Otherwise the most remarkable point is the occurrence of highly organised Gymnospermous stems, notably the genus *Callixylon*. This appears to have belonged to the *Pitys* group; the wood shows an exceptionally beautiful structure, comparable to that of the more advanced Conifers among living plants. In this case no seeds are known, but on anatomical evidence it seems clear that in Upper Devonian days, Gymnosperms had already attained a high grade of organisation.

When we get back still further, to the Early (Middle and Lower) Devonian, the period of the oldest known land flora, we find no conclusive evidence for the existence either of Pteridosperms or ferns. Fossils resembling the naked rachis of a fern-frond are known, but they cannot be certainly distinguished from the branched, undifferentiated thallus which in those days was the form assumed by many of the archaic vascular plants. The extraordinarily simple organisation of some of these early types has been fully revealed by recent work, especially that of Kidston and Lang.

Side by side with this primitive vegetation, however, plants of a much higher grade occur. The most famous of these is Hugh Miller's "cone-bearing tree," which he discovered some eighty years ago, in the Middle Old Red Sandstone of Cromarty.

Miller inferred its affinities from the structure of the wood. This has recently been re-investigated by Kidston and Lang. It is a highly organised type of wood, differing in some respects from that of known Gymnosperms, but, in the opinion of the present writer, more like a Gymnosperm than anything else. Thus it is possible, though not yet proved, that seed-plants may have already existed in the earliest land-flora of which we have any knowledge, and contemporary with the simplest land-plants, of a thalloid, Alga-like habit.

On the existing evidence we have no right to assume that the ferns preceded the seed-plants in their appearance on the earth. It may be that the phylum of the Spermophyta is as old as any known line of vascular Cryptogams. We may still hold to the belief that the seed-plants must have been derived from some race of heterosporous spore-plants. But what these supposed ancestors actually were is totally unknown. We may feel fairly sure that the progenitors of the Spermophyta belonged to a primitive stock, wholly unlike any of the higher Cryptogamic families, with which they have hitherto been compared.

[In preparing this article some use has been made, with the sanction of the University College of Wales, of the writer's paper "On the Origin of the Seed-plants," published in "Aberystwyth Studies," Vol. IV., 1922. The article cited deals with the question from a somewhat more technical point of view.]

GUIDE TO THE EXHIBITS IN THE SCIENCE GALLERIES

ARRANGED BY A COMMITTEE
OF THE ROYAL SOCIETY

PRICE SIXPENCE

INTRODUCTION.

THE Science Exhibition forms part of the scheme for Government participation in the British Empire Exhibition, and has been organised, with funds provided through the Department of Overseas Trade, by the Royal Society.

On the invitation of the Inter-Departmental Committee responsible for Government participation, the Council of the Royal Society appointed a British Empire Exhibition Committee, under the Chairmanship (1925) of Mr. F. E. Smith, C.B.E., F.R.S., to arrange the Exhibition. This committee is constituted as follows:

Mr. F. E. Smith, C.B.E., F.R.S., *Chairman.*
Sir Herbert Jackson, K.B.E., F.R.S., *Vice-Chairman.*
Sir Oliver Lodge, D.Sc., Sc.D., LL.D., F.R.S., *Vice-Chairman.*
Mr. C. V. Boys. F.R.S.
Sir William Bragg, K.B.E., M.A., D.Sc., F.R.S.
Sir Dugald Clerk, K.B.E., D.Sc., LL.D., F.R.S.
Mr. J. W. Evans, C.B.E., D.Sc., LL.B., F.R.S.
Sir Richard Glazebrook, K.C.B., M.A., Sc.D., F.R.S.
Sir Richard Gregory, D.Sc.
Sir Daniel Hall, K.C.B., M.A., LL.D., F.R.S.
Mr. D. T. Harris, M.B., B.S., Ch.B.
Major E. O. Henrici, R.E. (retired).
Col. H. G. Lyons, R.E. (retired), D.Sc., Sc.D., F.R.S.
Sir Joseph Petavel, K.B.E., D.Sc., F.R.S.
Mr. C. Tate Regan, M.A., F.R.S.
Mr. A. B. Rendle, M.A., D.Sc., F.R.S.
Sir Robert Robertson, K.B.E., M.A., D.Sc., F.R.S.
Sir Arthur Schuster, Sc.D., D.Sc., LL.D., F.R.S.
Sir Napier Shaw, Sc.D., LL.D., D.Sc., F.R.S.
Mr. G. C. Simpson, D.Sc., F.R.S.
Mr. A. A. Campbell Swinton, F.R.S.
Prof. J. F. Thorpe, C.B.E., D.Sc., F.R.S.
Mr. W. J. U. Woolcock, C.B.E.
Mr. T. Martin, M.Sc., *Secretary.*

In many cases the exhibits are shown by the scientific men actually engaged in the work, and are supplemented by instrument loaned by some of the leading firms of scientific instrument makers. The majority of the exhibits are working demonstrations. Benches, fitted with gas, water and electricity, are provided, and a staff of scientific assistants are in attendance throughout the Exhibition. (The Demonstration benches by Messrs. Baird & Tatlock (London), Ltd.)

The arrangement of the principal section of the physical exhibits is based on the extended spectrum of electro-magnetic

oscillations and radiations. The experiments illustrate the phenomena met with in the different regions of the spectrum, from gamma rays and X-rays at one end, through the visible region, to wireless waves and slow oscillations at the other. As a key to these exhibits a large chart of the spectrum (described below) has been specially prepared and is displayed in the galleries.

The exhibit dealing with Solar and Terrestrial Radiation constitutes a link between the purely physical and the geophysical exhibits. These are arranged to illustrate recent British contributions to the sciences of Meteorology, Terrestrial Magnetism, Atmospheric Electricity and Seismology.

Biological science is represented by three groups of exhibits dealing respectively with Zoology, Botany and Physiology. The Zoological section illustrates principally recent research bearing on the theory of evolution. The botanical exhibits include illustrations of the preservation of colour in plants for exhibition purposes and experiments in plant physiology. In Physiology the theme is the application of physical methods and appliances in this science.

CHART SHOWING RANGE OF ELECTRO-MAGNETIC WAVES.

The chart is designed to show, in a manner which appeals to the eye, the whole range of radiations which are now known to be electro-magnetic. According to classical theory, all the types of radiation mentioned on the chart are propagated as strains in the ether of space with a constant velocity which is approximately equal to 30,000,000,000 centimetres per second. There is every reason to believe that the radiations shown on the chart, from the shortest gamma-ray having a wave-length of only 0·000 000 0002 centimetre up to wireless waves having a wave-length of 500,000 centimetres, travel in space with this fixed velocity, and that although their effects are very diverse, the only fundamental difference between the many types of radiation studied lies in the wave-length.

The whole range of radiations is divided for convenience into groups. Within any group the radiations are similar in their characteristic effects and properties, and the same methods may be employed to detect and produce a wave of any length within a group. The radiations of each group overlap to some extent, so that by changing our methods we may generate or detect all the waves shown on the chart, discarding one set of methods when we have succeeded in producing, say, the shortest wave of the group of radiations next above in the scale of wave-lengths. As an example of this, we may generate a radiation of wave-

length 0·02 centimetre either by the use of an Hertzian oscillator or by employing a source of heat radiation. Although the two sources of radiation are very different, the radiation itself is identical in all its properties.

Since a chart in which the lengths of the lines are made proportional to the wave-length would circle the earth very many times, a scale of octaves has been chosen, an octave implying that the numerical value of the wave-length has been doubled. The chart shows about 60 such octaves, and there is an unbroken series of radiations increasing in wave-length from gamma-rays to X-rays, through the ultra-violet and the visible rays to the infra-red, so to the Hertzian and wireless waves, finally ending with the very long waves corresponding to relatively slow electrical oscillations. The wave-lengths are given in centimetres and in Angström units. One Angström unit is equal to 0·000 000 01 centimetre. It is only recently that radiations have been discovered corresponding to all the wave-lengths shown in the chart. Scientists are now able to generate and detect ethereal (or electromagnetic) waves in any part of the spectrum. When one considers the vast range of wave-lengths covered by the chart, this is in itself a most remarkable achievement.

THE ATOM.

1. *Sir Joseph Thomson, O.M., F.R.S.* **The Atom.**

The Electron.

(*a*) Apparatus by which the existence of electrons was detected and their mass and velocity measured.

(*b*) The modified type of Perrin tube used by Sir Joseph Thomson in 1897 to show that, when a magnet was used to deflect the cathode rays, the negative electrification followed exactly the same course as the rays which produced the fluorescence on the glass.

2. *Sir Ernest Rutherford, O.M., F.R.S.*

Some Aspects of Radio-Activity and their Bearing on Atomic Structure.

(A) The Production of Radium Emanation.

The radium atom transforms with the emission of an *α*-particle into the atom of a gaseous substance, the radium emanation. The atom of the radium emanation is much more unstable than that of radium, so that the volume of the emanation in equilibrium with 1 gm. of radium is very small, only 0·6 cubic millimetre. A sufficient quantity of the emanation has been collected and isolated to enable its chemical and physical properties to be examined, and

to show that, apart from its radio-active properties, it behaves like the inert gases, helium, neon, argon, etc. Its atomic weight is 222, and its boiling point is -65° C. at atmospheric pressure. (At the low pressures at which it is generally used, its boiling point is about -150° C.)

(B) The Discovery of the Nature of the α-Particle.

In the earlier history of radio-activity, little attention was given to the study of the α-rays, and their importance was not generally recognised. Thus some years elapsed before the nature of the rays was disclosed. It was suggested by various workers that the α-rays might consist of positively charged bodies projected with great speed. They should therefore be deviated in magnetic and electrostatic fields. The earlier attempts to show this deviation were unsuccessful owing to the extreme smallness of the effect. In 1902, however, Rutherford was able to show that the α-rays were deflected in a magnetic field in the opposite sense to the cathode or β-rays. Later he succeeded in measuring the deflexion by an electrostatic field, and also in showing that the α-particles carried a positive charge, by collecting the charge of a large number of α-particles in a Faraday cylinder. Combining the magnetic deflexion, which measures mv/e, with the electrostatic deflexion, which measures mv^2/e, he obtained v, the velocity of the particle, and e/m, the ratio of its charge to its mass. The magnitude of the value of e/m indicated that, if the α-particle consisted of any known kind of matter, it must either be hydrogen or helium, and the observed production of helium by radium and its emanation lent weight to the latter suggestion. This was confirmed by direct experiment by Rutherford and Royds, who showed that accumulated α-particles formed a gas which gave the spectrum of helium.

(C) The Counting of α-Particles.

There are two direct methods of detecting a single α-particle, the electrical method and the scintillation method.

The electrical method depends on the principle of ionisation by collision. In the first form of α-ray counter, due to Rutherford and Geiger, the pressure of the gas in an ionisation chamber and the voltage between the electrodes were adjusted so that any ions produced in the gas were multiplied several thousand times by collision. The magnification was so great that the entrance of a single α-particle into the chamber produced a measurable current.

A counter devised by Geiger has the advantage that the gas in the counter may be at atmospheric pressure and that even greater magnification is obtained.

When a screen of phosphorescent zinc sulphide is exposed to α-rays, a luminosity is produced which, examined under a microscope, is found to consist of scintillating points of light, which come and go with great rapidity. Each scintillation

corresponds to the impact of an a-particle on a zinc sulphide crystal. On a uniform screen every a-particle produces a visible scintillation, so that we have an extremely simple method of counting a-particles. As zinc sulphide gives only a weak general luminosity when exposed to β- or γ-rays, the counting of a-particles by this method is, up to a certain limit, independent of β- and γ-ray effect. This gives the scintillation method a great advantage over the electrical method.

The screen is made by dusting a thin layer of small zinc sulphide crystals on a cover-slip moistened with a trace of oil or adhesive material. The observation of the scintillations is carried out in a darkened room.

The String Electrometer by the CAMBRIDGE INSTRUMENT CO., LTD.

DEMONSTRATION of scintillations.

(D) The Scattering of a-Particles.

The a-particle travels through matter in general in a straight line, its energy of motion being so great that intense forces are necessary to deflect it; but occasionally an a-particle suffers a deflexion through a large angle in an encounter with a single atom. In order to account for these large deflexions Rutherford put forward, in 1911, the theory of the nuclear constitution of the atom. On this theory, the whole of the positive charge associated with the atom is concentrated in a minute, but heavy nucleus, while the negative charge is made up of electrons distributed over a space surrounding the nucleus comparable with the size of the atom, as usually understood. Owing to its large positive charge the nucleus of a heavy atom, like gold, is surrounded by an intense electric field, and if an a-particle enters this field it will be deflected from its straight path. Assuming that the electric force around the nucleus varies inversely as the square of the distance, Rutherford obtained the relations connecting the fraction of a-particles scattered through any angle with the charge on the nucleus and the velocity of the a-particle.

These relations were tested by Geiger and Marsden in an extensive series of experiments. Their results were in remarkable agreement with Rutherford's calculations and proved conclusively the truth of the nuclear theory.

Later, Chadwick was able to show by accurate measurements of the scattering of a-particles that the charge on the nuclei of platinum, silver, and copper was given in electronic units by the atomic number of the element, and that the force at moderate distances from the nucleus varied inversely as the square of the distance.

The Atom.

(E) The Artificial Disintegration of Elements.

The first evidence of the artificial disintegration of an element was obtained by Rutherford in 1919. He found that when swift α-particles pass through dry air or nitrogen, a few long-range particles are produced which can be detected by their scintillations on a zinc sulphide screen. He concluded that some of the nitrogen atoms were disintegrated by the close collision with an α-particle, with the liberation of a hydrogen nucleus at a high speed. Later, Rutherford and Chadwick found that these particles have a greater range than the swift H nuclei set in motion by the collision of an α-particle with a hydrogen atom. For example, using radium-C as a source of α-rays, no H nuclei from hydrogen can be detected after passing through absorbing screens of aluminium or mica of stopping power equivalent to 30 cm. of air, while the maximum range of the particles from nitrogen corresponds to 40 cm. of air. This shows at once that the emission of particles from nitrogen cannot possibly be ascribed to the presence of free hydrogen or of hydrogen in combination as a contamination.

This observation gave a simple method of testing whether other elements besides nitrogen emitted long-range particles when bombarded by α-particles. If the scintillations are counted for absorptions greater than 30 cm. of air, the results are quite independent of the presence of hydrogen as an impurity in the substance under examination. In this way, definite proof of the disintegration of boron, nitrogen, fluorine, sodium, aluminium, and phosphorus was obtained.

In further experiments it was found that neon, magnesium, silicon, sulphur, chlorine, argon, and potassium are also disintegrated by the impact of swift α-particles. The H particles liberated from these elements are of shorter range and smaller in number than those ejected under similar conditions from the elements previously mentioned. Thus, with the two exceptions of carbon and oxygen, all the elements from boron to potassium have been disintegrated by bombardment with α-particles.

Recently, Blackett has photographed by the Wilson method the tracks in nitrogen of about 300,000 α-particles. Among these he found eight tracks which show the event of the disintegration of a nitrogen nucleus by an impinging α-particle. The striking point of these photographs is that such an α-ray track divides into two branches only. One branch is a fine straight track, along which the ionisation is distinctly less than along an α-ray track. This must be due to a particle of small charge and high velocity, and it is the path of the ejected H particle. The second arm of the fork is a short track similar in appearance to the track of a nitrogen nucleus, such as has been obtained in a normal elastic collision. This is the path of the nitrogen nucleus after disintegration. There is no sign of a third arm to correspond to the track of the α-particle itself after the collision. It is concluded, therefore, that the α-particle does not escape, but that in ejecting the H particle from the nitrogen nucleus, the α-particle is itself bound to the nucleus. Of the nature of the residual nucleus little can be said without further data.

(F) The Beta and Gamma Rays from Radio-active Substances.

If a radio-active source is placed in a uniform magnetic field, the β-rays which are ejected from it in directions at right angles to the lines of force travel in circles and leave a trace on a photographic plate. From the radius of the circle, the velocity of a homogeneous group of β-rays can be determined. The β-rays emitted are found to consist of a number of such groups of electrons of homogeneous velocity, characteristic of the element in question, together with electrons of continuously varying velocity. The latter probably include the electrons shot out from the nucleus in the disintegration. The homogeneous groups have been shown by Ellis to consist of electrons ejected from the K, L, M, etc., levels of the atom by the γ-rays, and since the ejection is governed by the law of photo-electric action, the wave-lengths of the lines in the γ-rays spectrum emitted by a disintegrating atom can be found. In the case of radium B, there is agreement between the wave-lengths so determined and those found by Rutherford and Andrade directly by the crystal method, but the β-ray method is applicable to much shorter wave-lengths. The existence of difference-relations between the quantum energies of the various groups of γ-rays emitted from radium B and radium C makes the applicability of quantum dynamics to the nucleus very probable, and a scheme of nuclear levels concerned with the emission of γ-rays can in each case be set up, in the same way that from a knowledge of the optical and X-ray wave-lengths the level structure of the atom may be determined.

(G) The Work of Moseley on the Atomic Number of the Elements.

Moseley found that the X-ray spectra of the elements depended on the square of a number which increased by unity in passing from one element to the next of higher atomic weight. This number was not exactly equal to the atomic number (*i.e.*, the number of the element when all the elements are arranged in order of increasing atomic weight), but was equal to $N-a$, where N is the atomic number and a a constant for the series. In order to obtain perfect regularity in the X-ray spectra, it was necessary to leave four places for unknown elements corresponding to atomic numbers 43, 61, 72 (the recently discovered hafnium), and 75, and to adjust the places of the elements A, Co, and Te, where the order of atomic weights clashed with the order of chemical properties. Then, in every case, from Al, for which N was assumed to be 13, to Au, $N = 79$, the X-ray spectra of an element were defined by the number assigned to it. On the nuclear theory of atomic structure this characteristic number must be closely connected with the charge on the nucleus, and Moseley concluded that the number gave in fundamental units the actual value of this charge.

In this way Moseley determined the number and order of the elements.

The Atom.

3. *Mr. D. R. Hartree.*

Models Illustrating Atomic Structure.

The present idea of the nature and structure of atoms, which is based mainly on the work of J. J. Thomson, Rutherford and Bohr, is roughly as follows:—An atom consists of a very small positively charged nucleus, which is responsible for most of the mass of the atom, surrounded by a number of electrons, of which some at least are at distances from the nucleus of the same order of magnitude as the radii of atoms deduced from other evidence (about 10 cm.), the linear dimensions of the nucleus and individual electrons being about 50,000 times smaller; thus the atom is an exceedingly empty and open structure (an exhibit of a diagrammatic model of a neon atom illustrates this). Also the charge on the nucleus (measured in such units that the charge on the electron is unity), which is equal to the number of electrons in the neutral atom, is also equal to the atomic number, or number associated with the atom when all the elements are arranged in order by means of their chemical properties and X-ray spectra, as in the periodic table, and numbered consecutively from 1 for hydrogen.

The electrons are supposed to be moving in orbits about the nucleus, so that in some ways the atom resembles the solar system. But there are several important differences between the solar system and the atom, apart from the difference of scale.

(1) In the solar system the forces are gravitational in origin, and for any planet the attraction of the sun is large compared to that of the other planets, so that to a first approximation the mutual forces between the planets need not be taken into account in calculating the orbit of any one of them. In an atom, however, the fields are electrical, and also the mutual forces of the electrons are by no means negligible compared to the force between the nucleus and any one of them.

(2) In the solar system the orbits of the planets all lie nearly in the same plane, those of the major planets are nearly circular, and each lies wholly outside those inside it. In an atom the orbit of each electron may perhaps be thought of as roughly plane, but the planes of different orbits have different orientations in space, the orbits are often not nearly circular but more nearly elliptical, and different orbits may interpenetrate (somewhat as the orbits of the periodic comets in the solar system penetrate into the regions of the orbits of the planets).

(3) Lastly, and most important, the possible states of motion of the solar system form a continuous set of states, so that if the system is disturbed, by however little, there is always a possible new state of motion, different from the initial state, which it can take up when the disturbance is removed. The possible states of motion of an atom form a discontinuous set of discrete states, which are known as the stationary states, so that if an atom is disturbed, it either changes over to some other one of the definite separate stationary states, or it returns *exactly* to its initial state when the disturbing influence is removed.

When an atom changes from one stationary state to another with emission or absorption of light (in the general sense of electro-magnetic radiation—*e.g.*, X-rays, ultra-violet and visible light, "radiant heat"), there is a close relation between the frequency of the light emitted or absorbed and the difference of energy of the stationary states. From the idea of stationary states and this relation alone, many of the phenomena of spectra can be explained. **The Atom.**

For an atom consisting of a nucleus and one electron it is possible to specify the conditions for the stationary states in a mathematical form, and work out their energies and so the spectrum arising from transitions between them; the agreement with the observed spectra, even down to the minutest details, is almost perfect. For atoms consisting of a nucleus and more than one electron, the mutual interactions of the various electrons complicate the problem so much that it is not yet possible to specify the conditions for a stationary state, and even if they could be specified, the working out of the energies of the stationary states would probably be very difficult. But it is possible to make some simplifications and obtain approximate results without going so far that they lose their significance.

Instead of treating the atom, as a whole, as a system the stationary states of which are to be found, we think of each individual orbit as a stationary state in the field of the nucleus and electrons in other orbits; and after some further approximations it is possible to state the conditions for a single orbit to be a stationary state. It appears, then, that each orbit can be specified approximately by two whole numbers, which are written n and k and called "quantum numbers"; the orbit so specified is usually referred to as an n_k orbit. The precise meaning of these numbers cannot be explained simply and shortly, but speaking very roughly, $n-k$ is a measure of the radial motion of the electron in its orbit (*i.e.*, motion in towards and out from the nucleus) and k is a measure of the angular motion (*i.e.*, motion round the nucleus); for example, in a circular orbit there is no radial motion, and n and k are equal. It is possible also to calculate approximately the sizes and shapes of orbits; the models of atoms exhibited have been made from such data.

The electrons occur in groups of orbits with the same quantum numbers; if there are enough electrons, there are two in the smallest orbits with $n = 1$, eight in the next largest with $n = 2$; the numbers in the groups with higher values of n are different for different atoms. The distribution of electrons among the orbits with the same value of n but different values of k, and the orientations of the different orbits, are still uncertain.

It will be seen from the models that lithium with three electrons has the completed group of two small 1_1 orbits and one electron in a very much larger orbit, which is also rather loosely bound; and sodium with 11 electrons has 2 and 8 respectively in the completed groups with $n = 1$ and 2 respectively, and again one in a very much larger and rather loosely bound orbit. The outermost electrons are mainly responsible for the chemical properties of the atoms, and the 1, 2 and 3 outer and rather loosely bound electrons of the atoms of sodium, magnesium and aluminium, the orbits of

The Atom.

which are shown in the models, are responsible for the single, double and triple electro-positive valencies of these atoms. The similarity of structure of lithium and sodium atoms is an example of the way in which present theories of atomic structure are explaining the regularities of the periodic system of the elements.

The models made at MANCHESTER UNIVERSITY PHYSICAL LABORATORY.

4. *Prof. W. L. Bragg, F.R.S., and Mr. D. R. Hartree.*

The Crystalline Structure of Rocksalt.

The model represents atoms of sodium and chlorine placed in the relative positions which they occupy in a crystal of sodium chloride, and with the form of the electronic orbits shown approximately by the curves. The whole model is constructed to a scale of 10 cm. to the Ångström unit, or a thousand million to one, in order that the relative dimensions of the spaces between the atoms and the atomic structures themselves may be appreciated. The sodium atom is the smaller and the chlorine atom the larger in the model. It is not possible to show all the inner electronic orbits in every case, as some of these are too small.

The model made at MANCHESTER UNIVERSITY PHYSICAL LABORATORY.

5. *Prof. C. T. R. Wilson, F.R.S.*

Cloud Method of Studying the Tracks of Ionising Particles.

Atoms or molecules from which electrons have been ejected (positive ions), and atoms or molecules to which such ejected electrons have attached themselves (negative ions), may be made individually visible by causing water to condense upon them. In a dust-free moist gas, in which a suitable degree of supersaturation is brought about by sudden expansion, water condenses on any ions which may be present and on them alone. The drops of water condensed on the ions may be photographed immediately after their formation.

In its passage through a gas, an ionising particle (an α- or β-particle emitted by a radio-active atom, or an electron ejected by X-radiation or otherwise from an ordinary atom) passes through a large number of atoms under conditions such that an electron is ejected. The positive and negative ions which are thus produced are left as a trail along the track of the ionising particle. This trail of ions may be made visible as a cloud of water-drops and photographed.

If two simultaneous photographs are taken from different directions, a three-dimensional study of the tracks may be made, stereoscopically or otherwise.

The Wilson Cloud Expansion Apparatus, to the modified design of Shimizu, by the CAMBRIDGE INSTRUMENT CO., LTD.

DEMONSTRATION.

6. *Clarendon Laboratory, University Museum, Oxford. (Prof. F. A. Lindemann, F.R.S., Mr. T. C. Keeley, and Mr. E. Bolton King.)*

A Method of making audible the Movement of a- and β-Particles in an Electric Field.

Radio-active substances send out a-, β- and γ-rays. a- rays are simply helium atoms which have lost two of their four electrons and are travelling at a very high speed (10–20,000 km. per sec.). β-rays are electrons moving at yet higher speeds (up to 295,000 km. per sec.). Owing to the very much larger mass of the a-particles compared with the β-particles (7,000 to 1), both of them, in spite of the difference in speed, possess much the same energy.

When one of these very rapidly moving particles strikes an atom, it usually breaks off one or more of the outer electrons, thus leaving the mutilated atom (or ion) with a positive charge. In an electric field these ions move, thus transferring charge and thereby forming an electric current. If the field is strong enough, the velocity of the ions rises to such a high value that they themselves can break electrons off other atoms, thus forming new ions which in their turn repeat the process. In this experiment, so powerful a field is maintained between the two electrodes, that the ions formed by one single a- or β- particle produce sufficient new ions to give a momentary current, which, when amplified, works a loud speaker.

Owing to their large size and comparatively low speed, a-particles can scarcely pass a molecule of air without ionising it, and are therefore braked and brought to a stop at a fairly definite range (3–8 cm.). They are absorbed by all but the thinnest sheets of light material, such as aluminium or paper. The smaller and more rapid β-particles have much larger and less well defined ranges owing to the different stopping powers which different parts of the molecules of air possess. For the same reason they can pass through comparatively thick sheets of material.

The loud speaker by MESSRS. S. G. BROWN, LTD.; the amplifier by MESSRS. H. W. SULLIVAN, LTD.; the valves and H.T. batteries used in this and other exhibits from the Clarendon Laboratory by the METROPOLITAN VICKERS ELECTRICAL CO., LTD., and MESSRS. SIEMENS, BROS. & CO., LTD., respectively.

DEMONSTRATION.

The Atom.

7. *Prof. J. Joly, F.R.S.*

Photographs of Pleochroic Haloes.

Pleochroic haloes appear in certain rock minerals (notably in brown mica) as minute circular markings. Under favourable conditions a central particle will be noticed. This contains radio-active elements, the α-radiations of which, by altering chemically the containing mineral, give rise to the haloes. The haloes are, in fact, spherical objects.

The outside dimensions of the halo depend on the penetration of the swiftest α-ray projected from the nucleus. Accordingly, it is easy to determine by measurement whether uranium or thorium is the parent radio-active element responsible for the halo. Haloes often show inner structure consisting of concentric rings. These represent spherical surfaces developed around the nucleus where the alteration (by ionisation) of the containing mineral attains special intensity.

The exhibit shows haloes due to uranium and to thorium. They are, of course, highly magnified. A uranium halo is 0·033 mm. in radial dimensions. A thorium halo measures 0·041 mm. Different stages of development are shown in the case of uranium haloes. The oldest haloes often show "reversal" corresponding to solarisation in over-exposed photographs. All haloes are very old and have been formed by the α-radiation from the nucleus extending over a period of not less than 50 million years. The younger rocks do not show haloes.

Three of the photographs are of haloes of unknown origin. Their measurements do not agree with the α-radiations of any known element.

(See *Phil. Trans. R.S.*, Vol. 217, pp. 51–79, and *Proc. R.S.*, A. Vol. 102, 1923.)

8. *Sir Joseph Thomson, O.M., F.R.S.*

Positive Rays.

Photographs of positive ray spectra, illustrating the positive ray method of chemical analysis. The line due to H_3 is to be seen on some of the plates, and that due to the isotope of neon on others.

9. *Dr. F. W. Aston, F.R.S.*

Isotopes and the Mass-Spectrograph.

Isotopes are elements having the same chemical properties but different atomic weights. They were first shown to exist among the products of radio-active disintegration by Soddy. This exhibit illustrates progress in the discovery of isotopes among the more common elements. This was first suggested by the two parabolas given by the element neon when subjected to Sir Joseph

Thomson's positive-ray analysis. They are clearly seen in the enlargement shown. This result indicated that neon had atoms of two different weights, 20 and 22, but the accuracy of the method was not sufficient to prove this conclusively. Further evidence in favour of this view was afforded by the partial separation by diffusion of the constituents of neon by Aston in 1913, which was demonstrated by means of the special microbalance exhibited. **The Atom.**

The matter was finally settled by the mass-spectrograph. This instrument, a model of which is exhibited, was devised by Aston in 1919. In it positive rays of atoms and molecules give separate focussed lines on a photographic plate, by which means *the weights of individual atoms can be determined with an accuracy of* 1 *part in* 1,000. Chlorine (At. Wt. 35·46) was shown to be composed of two isotopes, 35 and 37, and other elements were proved even more complex. Thus krypton has six isotopes, 78, 80, 82, 83, 84, 86. Mass-spectra obtained with these elements are shown. No less than 56 of the known elements have been successfully analysed by means of this instrument, and all have been shown to consist of atoms having *whole number weights*. This removes the last difficulty in accepting the conclusion that the atoms of all elements are themselves built of atoms of electricity.

The Mass-Spectrograph by Messrs. ADAM HILGER, LTD.

GAMMA RAYS.

10. *National Physical Laboratory.* (*Dr. E. A. Owen*). **Gamma Rays.**

Penetration of Metals by γ-rays.

Among the radiations emitted by radium is a group of rays, called γ-rays, which are X-rays possessing on the average a much shorter wave-length than those emitted by an X-ray bulb. As a consequence, the γ-rays possess the power of penetrating solids in an even more marked degree. The effect cannot be shown by fluorescent screens as with X-rays, but use is made of another property of these radiations—namely, that of ionising (or rendering conducting) the air through which they pass. Thus the charged leaf of a gold-leaf electroscope becomes discharged when the rays pass into the electroscope.

In the exhibit a specimen of radium is placed in the centre of a massive lead block provided with a small hole so that a beam of γ-rays falls on an electroscope. Blocks of lead, iron or brass, each 1 in. thick, which can be interposed in the beam, only partially cut down the rate of fall of the electroscope leaf, showing that an appreciable fraction of the radiation is able to pass completely through the block.

The radium provided by MESSRS. WATSON & SONS (ELECTRO-MEDICAL), LTD., representing the RADIUM BELGE (UNION MINIÈRE DU HAUT KATANGA).

DEMONSTRATION.

X-RAYS.

X-rays.

11. *Mr. F. D. Edwards.*

Electrical Discharge through a Large Tube during Reduction from Atmospheric Pressure to High Vacuum.

This demonstration illustrates, on a large scale, the very beautiful effects obtained when a current of electricity at high potential is passed through air and other gases at low pressure. By gradual exhaustion of the tube to the point where X-rays are produced, and finally to "hardness" or non-conductivity of the tube, the phenomena observed by Crookes and others, whose investigations led to the discovery of the rays by Röntgen, are shown.

The apparatus used includes: (1) Discharge tube 4 ft. 6 in. long with sealed-in electrodes; (2) induction coil and mercury interrupter; (3) 2-stage rotary oil pump and motor arranged as "backing" pump for a small mercury vapour diffusion pump (4) simple measuring instruments.

The experiment is started with the air in the tube at atmospheric pressure, when the high tension discharge sparks across the 10 in. gap between the terminals on the induction coil. As the pressure in the tube is reduced, the resistance of the remaining air falls, and vivid lightning-like discharges start from the electrodes. On further pumping a succession of phenomena are noticed in the tube:—

Low pressure arc—heating effect—deviation by magnet.
The negative glow—fluorescence.
The Faraday dark space.
Cathode glow.
Crookes dark space.
Striæ.
Cathode rays—phosphorescence—magnetic deviation—heating effect.
X-rays.
"Hardness" of tube—sparking at induction coil.

A number of smaller hermetically sealed tubes, illustrating experiments carried out by Sir William Crookes and others, are shown working.

(1) *De la Rive's apparatus*, showing the rotation of a luminous arc round a vertical electro-magnet.

(2) *Crookes' tubes.*—(*a*) An aluminium cross placed in the cathode stream casts a shadow on the tube wall. "Fatigue" of the glass is shown by removing the cross, when the glass phosphoresces most brightly where previously protected by the cross.

(*b*) A vane wheel is set in motion by the vigorous bombardment of the electron stream. The motion is reversed by interchanging cathode and anode.

(*c*) A narrow pencil of cathode "rays" grazes a vertical screen. The approach of a magnet causes the phosphorescent track to move up or down according to the nature of the pole presented. **X-rays.**

A water cooled X-ray tube is arranged to show the modern development of these appliances, and their application.

Apparatus by MESSRS. W. EDWARDS & CO.
DEMONSTRATION.

---

12. *National Physical Laboratory* (*Dr. G. W. C. Kaye*).

Transparency of Materials to X-rays.

As is well known, the X-rays possess the power of penetrating solids to an extent which depends on the thickness and density. A working exhibit shows visually the relative transparencies of some half-dozen elements ranging from carbon (graphite, density 1·6) to lead (density 11·4). X-rays are capable of exciting a fluorescent screen, and the density of the shadow cast by each element on such a screen serves as a measure of the absorption.

A number of X-ray photographs are also shown which illustrate the varying transparency of different materials to X-rays.

DEMONSTRATION.

---

13. *Röntgen Society.*

Historic X-ray Tubes.

1 and 3. Crookes' tubes, with lattice screen. Both made in 1879.
5. Pear shape tube as used by Röntgen.
12 and 13. Jackson's first focus tubes. Made 1896.
15. Tube with platinum anticathode and auxiliary anode.
19. Campbell Swinton's first heavy anode tube, with penny as anode.
22. Tube (Jackson type) with lengthened electrodes to prevent sparking over.
24. Tube with adjustable electrodes to vary hardness.
34. American tube with automatic regulator.
57. Lodge's metal tube.
Coolidge X-ray tube.

The tubes are selected from the collection of the Röntgen Society at the Science Museum. They are exhibited, with the kind permission of the Society, by arrangement with the Director of the Science Museum.

X-Rays.

14. *Sir William Bragg, K.B.E., F.R.S.*

The Analysis of Crystal Structure by X-rays.

The exhibit illustrates the application of X-rays to the analysis of crystal structure.

The whole exhibit comprises :—

(1) Two forms of spectrometer, one adapted for measurement by ionisation methods, the other by photographic methods.

(*a*) *The Bragg Ionisation Spectrometer.*

In this instrument the intensity of the rays reflected at a crystal face is measured with an ionisation chamber which is capable of rotation about the axis of the spectrometer.

(*b*) *The Müller Spectrograph.*

The X-rays after reflection by the crystals fall in this case on a photographic plate. This gives a permanent record of all the possible reflections from the crystal planes. A knowledge of the positions and intensities of the reflected beams, which is supplied by the above methods of measurement, enables the relative positions of the atoms in the crystal to be determined.

(2) Some of the photographs obtained by the use of the latter instrument.

(3) Models representing the arrangement of the atoms in crystals of (*a*) diamond, (*b*) naphthalene, (*c*) long-chain molecules.

The Bragg Ionisation Spectrometer by MESSRS. W. G. PYE & CO., the Müller Spectrograph by MESSRS. ADAM HILGER, LTD. X-ray tube as used for the investigation of crystal structures provided by Dr. G. Shearer.

ULTRA-VIOLET RAYS.

Ultra-Violet Rays.

15. *Clarendon Laboratory, University Museum, Oxford (Prof. F. A. Lindemann, F.R.S., Mr. T. C. Keeley and Mr. E. Bolton King).*

Schumann X-Rays.

The energy of electrons ejected from metals under the influence of radiation is equal initially to the energy of the quantum of the radiation concerned. This quantum is simply proportional to the frequency, so that red light ejects comparatively slow electrons, whereas violet light ejects electrons of twice the energy, or $\sqrt{2}$ times the velocity. If the metal exposed to the light is insulated, on losing electrons it acquires a positive charge which attracts the electrons and tends to slow them up, and ultimately, when the charge is high enough, prevents them from escaping altogether. Hence an insulated piece of metal will acquire a charge proportional to the frequency of the incident light.

Ultra-Violet Rays.

In this experiment, it is shown that an insulated electrode connected to an electrometer acquires a charge of some three volts when exposed to visible light. When exposed to radiation produced by stopping electrons the velocity of which corresponds to a potential drop of some hundred volts, the electrode charges up to a potential of the same order as that producing the radiation. Under the influence of X-rays, the electrode charges up to thousands of volts, and the radiation shown in this experiment is therefore of a frequency intermediate between X-rays and the ultra-violet. This is the region of the spectrum which in ill-informed circles is said to include the "death-ray." It will be noted that the whole of the experiment has to be carried out in a vacuum, as the slightest trace of air entirely absorbs radiation of this frequency.

DEMONSTRATION.

16. *National Physical Laboratory* (*Dr. G. W. C. Kaye*).

Fluorescence by Ultra-Violet Light.

Ultra-violet light possesses the property of causing certain materials to fluoresce brilliantly. In the exhibit, the light from a quartz mercury-vapour lamp is passed through a sheet of Wood's glass which removes the visible radiation. The residual ultra-violet light is received by a variety of fluorescent materials.

The late Sir William Abney's fluorescent tubes exhibited by Prof. A. Fowler, F.R.S.

DEMONSTRATION.

17. *Sir Herbert Jackson, K.B.E., F.R.S.*

Focus of Ultra-Violet Radiations shown on Phosphorescent Screens.

The rays from a condensed spark between aluminium electrodes are caused to converge by a quartz lens. A focus of the rays in the visible spectrum is obtained on the screen at about two feet from the lens. This represents the focus of radiations of wave-lengths from about 7000 Å.U. to 4000 Å.U. By moving the screen nearer to the lens a smaller focussed image of the spark is obtained at a distance of about 8 in. from the lens. This shows the focus of rays of short wave-length, mainly 1860–1850 Å.U. On one of the screens (zinc silicate) the image is green: on the other screen (zinc phosphate) the image is red. These colours represent the phosphorescent response of the materials of the screen to short invisible wave-lengths. The materials of the screen are chosen to give only very slight phosphorescent response to the radiations intermediate between visible violet and the wave-lengths given above. To such wave-lengths the thinnest film of glass is entirely opaque.

DEMONSTRATION.

VISIBLE RAYS.

Visible Rays.

18. *Prof. L. R. Wilberforce.*

Apparatus for Studying the Motion of Waves.

The main interest of the experiments shown is in the illustrations they furnish of problems in the wave theory of light and of other electro-magnetic radiations.

The waves are produced on the surface of water in a shallow trough by dippers of appropriate form attached to an electrically maintained tuning-fork. The trough has a glass bottom, a converging beam of light is sent upwards through it, passed through a convex lens and reflected by a mirror so that an image of the liquid surface is formed on a screen. The light is intermittently transmitted by a slotted disc coupled to a phonic wheel which is driven by the current supplied to the fork. The coupling is given by the fluid friction of oil between two coaxial cylinders, and its effect is to damp out irregularities of motion in the phonic wheel and to give the disc a uniform rotation slower than that of the wheel. The difference of speed, initially due to air friction, can be increased at will be producing a suitable magnetic field to be traversed by the disc.

The effect of the intermittent illumination is that the waves appear stroboscopically to have a motion so slow that their details can be readily studied. The speed of this apparent motion can be increased if desired by the action of the magnetic field. By the use of double dippers the phenomena of interference are shown. The formation of shadows, reflection, the production of stationary waves and the passage of waves through apertures greater or smaller than the wave-length, can be studied by the use of movable partitions. The fusion of secondary wavelets into a wave-front and the action of the diffraction grating can be illustrated by comb-shaped dippers. The convergence of waves to a focus can be produced by a concave dipper. The refraction of waves due to change of velocity can be demonstrated by producing suitable local variations of depth.

DEMONSTRATION.

---

19. *National Physical Laboratory (Mr. J. Guild).*

Projected Spectrum.

A continuous spectrum, produced by refraction by a prism of calcite, is projected on a screen. This is intended to show—

(*a*) The properties of the visible spectrum :—

(i) The variation of the refractive index of transparent material with the wave-length of the radiation is exemplified by the fact of the formation of the spectrum instead of a white image of the slit.

(ii) The variation of colour of the sensation produced by radiation of different wave-lengths is shown by the sequence red, orange, yellow, green, green-blue, blue, violet, in descending order of wave-length. **Visible Rays.**

(iii) The origin of the colours of materials is shown to be due to the fact that the light leaving the coloured material is relatively deficient in some parts of the spectrum. By interposing various coloured glasses, etc., in the path of the beam, the effect on the spectrum which gives rise to the colour can be observed.

(iv) The action of a diffraction grating is illustrated by crossing the prism with a coarse grating. The separation of the various orders of the diffracted images are seen to depend on the wave-length, being approximately twice as great for the red end of the visible spectrum as for the blue end. This dependence of separation on wave-length is the basis of one method of measuring wave-length.

(*b*) The existence of radiation in parts of the spectrum outside the region which gives rise to the sensation of light:

(i) By inserting a screen coated with zinc sulphide, a material which has the property of glowing with a green light when radiation of shorter wave-length than visible light falls on it, the presence of such radiation beyond the violet end of the visible range (the "ultra-violet" region), is demonstrated.

(ii) By means of a thermopile and galvanometer it is shown that the energy of radiation on being absorbed heats the absorbing material. The relative amounts of energy in different regions of the spectrum are shown to vary considerably, and the existence of radiation beyond the red end of the spectrum (the "infra-red" region), is demonstrated.

The Moll Thermopile and Galvanometer by the CAMBRIDGE INSTRUMENT CO., LTD., the phosphorescent screen prepared by Mr. T. Haigh.

DEMONSTRATION.

---

20. *Clarendon Laboratory, University Museum, Oxford (Prof. F. A. Lindemann, F.R.S., Mr. T. C. Keeley and Mr. E. Bolton King).*

Photo-electricity.

The emission of electrons under the influence of light, the so-called photo-electric effect, can be applied to a large number of scientific and industrial uses which involve comparison and measurement of light intensities. It has been shown that the current from a properly designed cell is proportional to the light intensity over a large range, and the sensitivity of the cell is of the same order

Visible Rays.

as that of the eye. The metal used in the cell depends on the wave-length of the light to be measured, the alkali metals being usually employed, as they are most sensitive in the neighbourhood of the visible spectrum ; the most effective wave-length varies from about 3400 Å.U. for sodium to 5500 Å.U. for caesium. The cell is usually filled with an inert gas such as neon, at a small pressure, and an accelerating potential applied, so that the current is magnified by the ions formed by collision between the accelerated electrons and the molecules of the gas.

In the experiment a photo-electric cell with a suitable accelerating potential is connected to a galvanometer. When the light is switched on, a current flows through the galvanometer proportional to the intensity of illumination. This may be checked by inserting between the lamp and the cell a piece of metal gauze which cuts off 50 per cent. of the light.

DEMONSTRATION.

---

21. *Royal Observatory, Edinburgh.*

Photograms of Stellar Spectra.

These prints are autographic reproductions from spectra taken with a prismatic camera—prism, 12° angle, telescope, photo-visual object glass of 6 in. aperture and 100 in. focal length. The spectra between *C* and *K* are about 1 in. in length. The reproduction is made by passing the spectrum through a Koch photo-electric photometer constructed for the purpose at the Observatory. They are chiefly designed for measuring the partition of energy throughout the spectrum, for the purpose of reading stellar temperatures. The measures are made by a method described in Monthly Notices Roy. Ast. Soc. 85 (1925), p. 211, which eliminates the photographic peculiarities of the plate and other adventitious effects.

The stars represented are :—

ϵ Orionis	B0	α Cassiopeiae	K0
γ Ursae Majoris	A0	Draconis	K5
ϵ Aurigae	F5	β Pegasi	M3
α Aurigae	G0		

The progressive entry and disappearance of the hydrogen series will be noticed, followed by the increasing prominence of metallic lines, especially the *H* and *K* lines of calcium, and the *G* band, and finally the titanium oxide bands, with a general absorption which leaves virtually the whole radiation in the red.

22. *National Physical Laboratory (Mr. T. H. Harrison).* **Visible Rays.**

Colour Sensitivity of Photo-Electric Cells.

Before comparing the candle powers of electric lamps photo-electrically it is essential that they should operate at the same colour distribution, and in order to obtain the full accuracy of the photo-electric method, the colour-matching must be done by a method more sensitive than the visual one. A method of colour matching has been developed by the staff of the Research Laboratories of the General Electric Company, and is being adopted at the National Physical Laboratory as a preliminary to the accurate standardisation of electric lamps. A rubidium and a sodium cell are connected in series and the photo-electric currents balanced against each other when the two cells are exposed to the illumination of the same electric lamp. If the temperature of the lamp is raised the sodium cell becomes relatively more sensitive and *vice versâ*. By this method lamps can be colour-matched to within 1° K. of their equivalent temperature and within 0·1 per cent. voltage.

Dolezalek Electometer by the CAMBRIDGE INSTRUMENT CO., LTD.; Photo-Electric Cells by the GENERAL ELECTRIC CO., LTD.

DEMONSTRATION.

---

23. *Prof. F. Horton, F.R.S., and Dr. Ann C. Davies*

The Excitation of the Spectra of Gases by Electron Impacts.

The apparatus consists of a small glass vessel supported between the poles of an electromagnet. The vessel contains the gas to be experimented upon at a low pressure, usually a few tenths of a millimetre. Sealed into the vessel are two parallel, lime-coated platinum filaments which are heated electrically, one at a time, and supply the electrons for the bombardment of the gas. A short distance beneath the two filaments a circular grid of fine mesh platinum gauze is situated, while a circular disc of platinum is placed parallel to and concentric with the grid at a distance of about 1·5 cm. from it.

The electrons from the filament are accelerated towards the grid by means of a potential difference supplied by a battery connected to these two electrodes outside the apparatus. Some of the electrons pass through the interstices of the gauze into the space between the grid and the disc, where they collide with gas atoms. The production of luminosity results from the recovery of the atoms after such impacts. The magnetic field in which the apparatus is situated concentrates the luminosity into a bright

Visible Rays.

central column between the grid and the disc, and by directing the slit of the spectroscope towards this column, and watching for changes in the spectrum of the luminosity as the potential difference applied between the filament and the grid is gradually increased, the voltages necessary for the excitation of different groups of lines can be determined. For such an investigation, the grid and the disc would be connected together outside the apparatus.

By employing a second battery so as to accelerate or to retard the electrons as they travel between the grid and the disc, the luminous column can be made to exhibit marked differences of colour along its length because of the different values of the electron energy at different distances below the grid.

Spectroscope by MESSRS. ADAM HILGER, LTD.; laboratory stand by MESSRS. W. G. PYE & CO.; electrical instruments by the WHITE ELECTRICAL INSTRUMENT CO., LTD.

DEMONSTRATION.

---

24. *Dr. W. E. Curtis.*

Origin of Spectra.

When a luminous source is examined with the aid of a spectroscope, which analyses the light into its constituent colours, spreading it out into a so-called spectrum, the latter is usually found to be more or less complex. Each colour manifests itself as a line in a particular position in the spectrum, and there are often hundreds of such lines. But the complexity is to some extent relieved by the fact that each substance participating in the emission of light gives a set of lines which are in perfectly definite positions, so that after acquiring sufficient experience of spectra, we can utilise measurements of the positions of the lines for obtaining information as to the chemical composition of the luminous source. Hence the original designation of this science, "spectrum analysis." But while it is true that a particular line can always be attributed to a particular substance and no other, yet one substance may give rise to several totally distinct groups of lines, according to the circumstances in which it is rendered luminous. Thus, for example, an element may emit a different spectrum according to whether it is vapourised in a flame or in an electric arc, or again, supposing it to be a gas and to be enclosed in a tube through which a high tension electric discharge is passed, the spectrum may be radically altered by altering the intensity of the discharge.

As regards the precise nature of the emission process, although the last few years have seen great advances in our knowledge, it is as yet far from complete. In particular, it is unable to suggest any simple mental picture of the phenomenon; there is not even any familiar analogy which would help to render an explanation intelligible. All that one can say is that the emission of a spectrum line appears to be the result of an abrupt change in the configuration of the atom or molecule. In the former case this change

consists simply in the transference of an electron from one orbit to another. In the latter case the change affects not only the electrons but also the speed of rotation of the molecule and the magnitude of the vibrations of the atomic nuclei from which it is built up. The molecule therefore gives a more complex spectrum than the atom; there are many more lines, and further, they are arranged in a different manner. We may thus broadly divide spectra into two classes—so-called *line spectra*, which are due to atoms, and *band spectra*, which are due to molecules. Several of the points touched on above are illustrated in the demonstration of the line and band spectra of nitrogen.

Line and Band Spectra of Nitrogen.

The discharge tube contains nitrogen at low pressure; this is made to glow by passing through it an electric current from an induction coil. By connecting a condenser in circuit a much more powerful discharge may be produced. It will be seen that—

(1) The "uncondensed" discharge gives a glow of reddish colour, which when analysed by the spectroscope is found to consist of a number of regularly spaced "bands" (which are actually composed of numerous lines very close together) in the red, yellow and green, and several in the blue, much farther apart.

(2) The condensed discharge presents quite a different appearance and is bluish in colour. The spectroscope shows that this is because the bands have disappeared and have been replaced by lines which exhibit no obvious regularity of arrangement.

The explanation is as follows:—

In (1) the nitrogen is in its normal state—*i.e.*, the atoms are associated in pairs or molecules, and a molecule always gives a band spectrum.

In (2) the powerful discharge has broken up these molecules into their component atoms, and an atom necessarily gives a line spectrum.

Induction coil by the COX CAVENDISH ELECTRICAL CO. (1924), LTD.; spectroscope by MESSRS. ADAM HILGER, LTD.

DEMONSTRATION.

---

25. *Prof. A. Fowler, F.R.S.*

Types of Spectra (Visible Rays).

(i) *Band Spectrum.*

The appearance of a band spectrum is illustrated by the bands of calcium fluoride, as produced in an arc between commercial "flame carbons" which are charged with this compound. It should be

Visible Rays.

noted that the calcium fluoride is partially dissociated in the arc, so that lines originating in atoms of calcium appear in addition to bands due to molecules of the undissociated compound.

(ii) *Line Spectrum.*

(*a*) Lines of iron appearing in the spectrum of an arc between two rods of iron.

(*b*) Lines of helium and neon appearing in the spectrum of the electric discharge through "vacuum tubes" containing these gases at low pressures.

(iii) *The Solar Spectrum.*

The spectrum of sunlight consists of dark lines (the "Fraunhofer lines") on a background of continuous spectrum. These lines are due to absorption by the luminous gases and metallic vapours surrounding the bright interior of the sun, which, if it could be observed alone, would yield a continuous spectrum. The dark lines occupy the same positions as the bright lines emitted by the gases and vapours themselves. The experimental arrangement shows the coincidence of the dark "*D*" lines of the solar spectrum with the bright yellow lines of a sodium flame, from which it is deduced that sodium is a constituent of the sun's atmosphere.

Apparatus for demonstrating the spectra of helium and neon by MESSRS. ADAM HILGER, LTD.

DEMONSTRATION.

---

26. *Dominion Astrophysical Observatory, British Columbia (Dr. J. S. Plaskett, F.R.S.).*

Astronomical Photographs.

(i) *Star Cluster in Herculis.*

Enlarged 4·5 diameters from the original negative, which was exposed for 60 minutes on Seed 30 plate on the 72-in. reflector. Distance of cluster, some 30,000 light-years.

(ii) *Ring Nebula in Lyra.*

Enlargement 8 diameters from original negative which was exposed for 25 minutes on Seed 23 plate on 72-in. reflector. Probable distance of Nebula, 800 light-years.

(iii) *Absorption Spectra of* 0-*Type.*

Examples of spectra, enlarged 14 diameters, of the 0-type stars, the hottest, brightest and most massive of the stars. Example of spectral subdivisions according to classification of H. H. Plaskett.

(iv) *Emission, Wolf Rayet Spectra of* 0-*Type.*

Examples of spectra, enlarged 14 diameters, of the Wolf Rayet stars arranged in order of decreasing excitation.

(v) *Spectra of* 5° 1267—*Variable Spectrum.*

Spectra, enlarged 10 diameters, of this remarkable star showing changes of spectrum on 4 different dates. Type B3e on October 9th to A2ep on March 25th, and back to B5e on April 10th. Spectra of P Cygni and *a* Cygni above and below.

(vi) 0-*Type Spectra in the Ultra-violet.*

Spectra obtained with Hilger ultra-violet spectrograph attached to 72-in. reflector, enlarged 12 diameters. Emmission spectra arranged in order of excitation.

---

27. *Mr. F. Twyman, F.R.S.*

Michelson Interferometer (Wave-Length Measurement).

The Michelson interferometer illustrates the principle of the apparatus whereby Michelson carried out, in 1892 and 1893, his measurements of the wave-length of the cadmium radiation in terms of the metre (*Trav. et Mem. du Bureau International des Poids et Mesures*, 11, 1895); and the optical system is very much the same as that used by Michelson and Morley in their classical attempt to find an effect of the earth's velocity on the velocity of light.

The instrument is arranged to give a demonstration of the interference ring system seen with a neon lamp. When one ring is replaced by another of the same colour, it shows that the moveable mirror has traversed a distance of approximately 0·00001 in.

It is obvious, therefore, that by counting the rings, one can effect any desired change of position of the moveable mirror. Michelson elaborated, however, an ingenious routine whereby the bands only required to be counted over a length of 10 cm. The principles of his method, particulars of which are too long to be given here, will be found in his book "Light Waves and their Uses."

Apparatus by MESSRS. ADAM HILGER, LTD.

DEMONSTRATION.

---

28. *Mr. William Gamble.*

The Lippmann Interference Process of Colour Photography.

The Lippmann process, invented by the late Prof. Gabriel Lippmann, of Paris, is based on the theory first propounded by Zenker of stationary light waves in the phenomena of interference. He obtained within the thickness of the photographic film a record of colour waves in the form of a series of extremely thin layers of silver deposit, separated by equally thin layers of no deposit—merely the clear layers of gelatine in which the silver had been emulsified. When these layers are looked at in light falling on them at a suitable angle, they show colours just as in a soap bubble, owing to the light reflected from one layer interfering with that reflected from the next.

Visible Rays.

To produce photographs in colour Lippmann prepared plates with an extremely thin film of silver emulsion and backed them in the dark slide of the camera with a film of mercury which acted as a mirror, causing the light coming through the lens and passing through the transparent film of the plate to be reflected back on itself. The effect was that where the reflected ray and the incident ray reinforced one another at the points at which the crests of both their waves coincided, there would be the greatest amount of light action, and where they opposed one another there would be darkness—consequently no photographic action. The result was that the film on the plate consisted of light and dark layers separated by distances proportional to their wave-lengths. For example, the parts of the film thus acted upon, corresponding to the red parts of the object photographed, being formed by the red rays, would have their layers farther apart than those corresponding to the violet parts formed by the shorter waves, other colours being rendered by intermediate layers. The fact that such layers actually existed has been proved by cutting a section of the film and reproducing it by photomicrography, thus distinctly showing the layers in dark bands. Looked at by transmitted light the plates have no definite colours, being grey like an ordinary photographic negative, but with a reddish tinge, but when examined under light falling at a suitable angle, and with a black background under the plate, the natural colours of the object are seen most brilliantly, as the specimens show.

The examples shown by Mr. Gamble include one, a reproduction of an old print, prepared by Prof. G. Lippmann. Others have been kindly lent by Prof. A. Fowler, F.R.S., Mr. T. Rheinberg and Mr. E. Senior.

---

29. *Prof. A. O. Rankine.*

(A) Diffraction of Light: Effects in the Shadow of a Spherical Obstacle.

In the centre of the shadow of a truly spherical object formed by a point source of light, a luminous spot is seen. This is due to the fact the light waves curling round the edges of the sphere reach the central spot by equal paths, and are thus in a condition to reinforce one another, so that the combined effect is great. Elsewhere in the shadow the paths are not equal for all the diffracted waves, and mutual interference produces practical extinction.

If the source is not strictly a point, as is impossible in practice, each point of the source produces a corresponding luminous spot in the shadow, with the result that there appears in the shadow an image of the whole source having the same shape as the source, but inverted. This effect was first noticed by Prof. A. W. Porter. The spherical obstacle thus behaves like a lens, the relation between the size of the image and the size of the source being the same as for a lens. The amount of light available is, of course, very small.

The exhibit demonstrates the effects for sources of various shapes such as a triangle, a square and a half-moon, and the images are seen on a ground glass screen. Photographs taken with the opaque ball mounted on a thin sheet of mica as an equivalent lens are also shown. The spherical object used is a ball such as is incorporated in ball-bearings, these balls being remarkably spherical. True sphericity is an essential condition for the success of the experiments. **Visible Rays.**

DEMONSTRATION.

(B) Interference of Light: Newton's Rings.

Newton noticed rings like those in the exhibit, before the wave theory of light, upon which their explanation depends, came to be generally accepted. The rings become visible when the interface between a flat glass plate and a slightly curved plate in contact with it is viewed by reflected (or transmitted) parallel light. The essential point is that the two surfaces should make very small angles with one another, so that they gradually separate as one passes away from the point of contact. The light undergoes partial reflection at both surfaces, and the light reaching the eye from a given point of incidence traverses different distances according to the amount of separation of the surfaces at the point in question. If this path difference is such that the waves are out of step by half a wave-length (or any odd number of half wave-lengths) destructive interference takes place, and the light of that particular wave-length is extinguished. Where, on the other hand, the difference of path is an *even* number of half wave-lengths, maximum light is seen. Thus one gets successive rings of luminosity and darkness in any particular colour; but since different colours have different wave-lengths, extinction does not take place in the same places for all. Viewed in white light coloured rings are therefore seen.

The effects are more striking if a single colour (or wave-length) is used. In the exhibit the source of light is the practically monochromatic radiation emitted by a sodium salt in a Bunsen flame. Many more rings are seen under these conditions than in white light.

An additional exhibit consists of two strips of plate glass clamped together at one end and separated by a very thin distance piece at the other. The interference fringes, which arise in the same way as already indicated, are in this case practically straight, extending across the strips. The necessity for such small distances of separation is due to the minute length of the light waves, about 0·000059 cm. for the sodium light.

DEMONSTRATION.

Visible Rays.

30. *National Physical Laboratory (Mr. J. S. Clark).*

Diffraction Gratings.

A diffraction grating consists of a very large number of equidistant and parallel straight lines, ruled by means of a diamond on a suitable plate of material, which may be glass, speculum, or gold, etc., according to the purpose for which the grating is intended. The ruling is accomplished by means of a very precise dividing engine, and the success of the grating depends on the parallelism and accuracy of spacing of the lines, and on the precision of form of the surface on which the lines (or grooves) are ruled.

The diffraction grating is used for analysing radiation (heat rays of long wave-length, visible and ultra-violet rays). Like a prism, it has the effect of separating the various wave-lengths falling upon it, the shorter being reflected at different angles from the longer, the whole of the reflected (or diffracted) band of wave-lengths constituting a spectrum.

(A) Plane Grating for General Work throughout the Visible and Ultra-Violet Regions of the Spectrum.

14,400 lines to the inch, ruled on a plane speculum blank.

The form of the ruled groove is such that all the lower orders (1st to 4th) of spectra are fairly bright for general use, but the 3rd order on one side of the normal is specially bright, so that the grating may be used in that order to obtain accurate wave-lengths using a known comparison spectrum.

(B) Concave Grating for General Work.

Similar to (A), but ruled on a concave speculum blank of 3 metres radius of curvature. The concave form does not require a lens to focus the spectra.

(C) Special Grating ruled on Gilt Brass, for Infra-red Work.

A plane grating of 2,400 lines to the inch ruled in gold deposited on a flat brass plate. The form of the ruled grooves is such that practically the whole of the original surface is removed by ruling, and the major portion of the incident light falling normally on the grating is diffracted into a limited region at an angle of about 15° on one side of the normal, corresponding to the 5th order spectrum of wave-length 5461 Å.U., or the 1st order of wave-length $2 \cdot 7\ \mu$.

(D) Concave Grating of 28,800 lines to the inch.

Ruled on a concave speculum plate of $1 \cdot 5$ metres radius of curvature, with twice the normal number of lines per inch. For use when high resolving power is required, and for the study of the shorter wave-lengths.

(E) Concave Grating of 2 metres Radius of Curvature.

Gratings of this size and type are also ruled on blanks of 1 and 1·5 metres radius of curvature.

The gratings are ruled at the NATIONAL PHYSICAL LABORATORY on the ruling engine constructed by the late Lord Blythswood, using blanks supplied by MESSRS. ADAM HILGER, LTD.

---

31. *Prof. Frederic J. Cheshire, C.B.E.*

Double Refraction.

Many transparent bodies, more especially crystalline ones, have what may be looked upon as optical grain, and as a consequence the ether waves which constitute light are transmitted by them more easily in some directions than in others. Double refraction results; that is, a beam of plane-polarised white light passing into such a crystal, in general, breaks up into two beams, which travel with different velocities, and in different directions, the vibrations in one beam taking place in a direction at right angles to those in the other. If these two beams be ultimately brought together again with their vibrations parallel to one another—as they are by an analyser—interference takes place, with the result that certain wave-lengths, or colours, are eliminated. If the linear retardation of one beam with respect to the other be equal to r, then between crossed nicols a series of wave-lengths equal in succession to $2r/1$, $2r/3$, $2r/5$, etc., will be eliminated, whilst between parallel nicols the series eliminated will be $2r/2$, $2r/4$, $2r/6$, etc.

In the examination of thin rock sections in polarised light, the different minerals which occur in the section have practically the same thickness, but the orientation of the direction of the grain and the refractive powers of the different minerals differ; hence the resultant retardations are different and the colours resulting therefrom.

(A) Spectro-Polariscope.

An apparatus for showing what happens to light in its passage through a bi-refracting substance, such as a cleavage lamina of selenite or mica. The apparatus is essentially a combination of a spectroscope and a polariscope. Light, after passing through a bi-refracting lamina between two nicol prisms, as in the ordinary polariscope, is decomposed spectroscopically by a direct-vision prism, so that a spectrum is projected upon the retina instead of an image of the object itself. In this way, the series of wave-lengths eliminated by interference, as explained above, can be seen as dark absorption bands occurring at intervals from one end of the spectrum to the other. The use of a double-image prism, correctly oriented as an analyser, gives two partially overlapping, vertically superposed

Visible Rays.

spectra corresponding to those given by crossed and parallel nicols respectively. Thus the dark bands in one spectrum occur opposite to bright bands in the other and, when the analyser is rotated through 90°, the dark and bright bands in each of the spectra exchange places.

The apparatus shown consists of a microscope stand, with a sub-stage polariser and a slit in place of the usual objective. This slit is collimated by a lens in the draw tube, above which is mounted a direct-vision prism, and above this again a double-image prism giving a small angular separation of the two images. The bi-refracting lamina is placed close against the slit. By this arrangement very sharp pictures can be obtained from rough cleavage lamina directly. Optical surfaces are no longer necessary.

DEMONSTRATION.

(B) Projection Polariscope.

Simple apparatus for demonstrating the application of polarised light to the differentiation and identification of minerals in sections of rocks, etc. The apparatus consists essentially of a low power projection microscope in which the object is illuminated with plane polarised light—a nicol prism polariser being mounted between the light source and the condensing lens, and the projection lens being combined with a second nicol prism to act as a polariser. Maximum brightness of a large angular field of view is secured by bringing the whole of the light which passes through the object to a focus in the projection lens itself. In this way a small arc can be made to give a picture large and bright enough for class demonstration.

DEMONSTRATION.

---

32. *Sir Herbert Jackson, K.B.E., F.R.S., and Mr. W. D. Haigh.*

Selective Absorption in the Visible Spectrum.

The example shown is a striking instance of selective absorption by a special glass rich in didymium oxides.

The spectroscope by MESSRS. ADAM HILGER, LTD.

DEMONSTRATION.

INFRA-RED RAYS.

Infra-Red Rays.

33. *Mr. F. Twyman, F.R.S.*

Infra-Red Spectrometer (Wave-length Measurement).

The instrument is used for measuring the wave-lengths of radiations in the infra-red. The radiation, which enters the instrument by a fine slit, as in an ordinary spectroscope, is dispersed into a spectrum by means of a prism of rocksalt, the spectrum being focussed on a thermopile. A galvanometer connected to the thermopile shows the intensity of the part of the spectrum under examination. The spectrum can be traversed across the thermopile by means of a fine screw, and the whole spectrum thus explored from 5,000 to 100,000 Å.U. (the visible part of the spectrum terminates at about 8,000 Å.U.). A bunsen burner emits a strong infra-red radiation in the neighbourhood of 44,000 Å.U., and this can be demonstrated on the instrument exhibited.

A photograph in the near infra-red, taken by the late Sir William Abney, kindly lent by Prof. A. Fowler, F.R.S.

Apparatus by MESSRS. ADAM HILGER, LTD.

DEMONSTRATION.

---

34. *Clarendon Laboratory, University Museum, Oxford (Prof. F. A. Lindemann, F.R.S., Mr. T. C. Keeley and Mr. E. Bolton King.).*

Photo-electric Effect in the Infra-Red. The Caesium Cell.

Caesium, which is characterised by the fact that its atom has one electron on an extremely eccentric orbit, is photo-electrically sensitive even in the infra-red, since this electron can be ejected from its orbit by the comparatively small quantum corresponding to low frequency radiation. Ebonite is transparent in the infra-red, and in this experiment the photo-electric current produced by radiation, from which all the visible light has been cut off by a thin sheet of ebonite, is shown by the charge it gives to an electrometer. The charge can leak away from the electrometer through a high resistance, and the potential of the electrometer at which this leak balances the inflowing electricity is a measure of the magnitude of this current.

DEMONSTRATION.

Infra-Red Rays.

34A. *Sir Robert Robertson, F.R.S., and Dr. J. J. Fox.*

Selective Absorption in the Infra-Red.

Many substances exhibit characteristic selective absorption in the near infra-red region of the spectrum (up to about 16μ). Carbon dioxide gas, for example, possesses infra-red absorption bands. The diagram shows the percentage transmission of carbon dioxide gas at 1⅓ atmospheres pressure, drawn from observations made by Sir R. Robertson, F.R.S., and Dr. J. J. Fox. The abscissæ represent wave-lengths, and the ordinates percentage transmission. The deep depressions in the curve of transmission are the bands, which are clearly seen at 11,000, 20,000, 27,700 and 43,200 A.U.

SHORT HERTZIAN WAVES.

Short Hertzian Waves.

35. *Mr. F. E. Smith, F.R.S.*

The Production of very short Hertzian Waves and Demonstration of their Heating Effect.

DEMONSTRATION.

---

36. *Sir William Bragg, K.B.E., F.R.S.*

Lindman's Apparatus designed to illustrate the Mechanism of Optical Activity (Rotatory Polarization) by Means of Electromagnetic Waves: the Apparatus can also be used to demonstrate other Polarization Phenomena.

It is known that optical activity is due to a special arrangement of the atoms in the molecule or the crystal. There is a screw which may either be right- or left-handed. In quartz and certain other crystals there are actually continuous spirals, running parallel to the crystal axis: in other substances the spirals are broken into fragments, and a very common arrangement is that of four carbon atoms placed at the four corners of a parallelopiped, the corners being chosen so that no two lie one side. Four such corners form, so to speak, one turn of a screw which may be either right- or left-handed. It is the screw-like arrangement which causes the rotation of the plane of polarisation of light when passing through the substance.

Lindman has illustrated these effects by the use of electromagnetic waves, which, though very short of their kind, are many thousands of times longer than the waves of light. The screw arrang ment that gives optical activity is replaced by actual metal spirals or by arrangements of metal spheres.

DEMONSTRATION.

WIRELESS WAVES.

37. *National Physical Laboratory (Mr. D. W. Dye).* **Wireless Waves.**

Determination of Frequency and Wave Form.

The measurement of frequency is of fundamental importance in wireless telegraphy. There are many methods by which this measurement can be made, and these are of two kinds: (1) absolute measurements, (2) secondary measurements. The absolute measurements are those in which the wireless frequency is referred more or less directly to a standard of time. The secondary methods of measurement include all those instruments and devices known as wave-meters.

Of the primary or absolute methods of measurements, those which have been developed in recent years to a high degree of precision may be termed harmonic methods. The principle underlying a harmonic method of measuring frequency is to correlate the unknown wireless frequency with a known higher or lower frequency in such a manner that the ratio of the two frequencies is an integer. If the integer is known—it may be such a number as 12, 50, etc.—then the wireless frequency under measurement is determined.

A primary method of this kind consists in superposing upon a time trace of known telephonic frequency, a displacement produced by the wireless frequency. The frequency of the wireless source is then smoothly and accurately adjusted until its value is an integral multiple of the telephonic frequency time trace. If the time trace takes the form of a circle or ellipse of considerable magnitude, whilst at the same time the wireless frequency is caused to produce a circular displacement of the agent producing the time trace, the result will be a closed looped figure when the two frequencies are harmonic to one another. By counting round or photographing the loops the wireless frequency becomes determined.

In the apparatus shown, a very steadily vibrating tuning-fork, having a frequency of 1,000 vibrations per second, produces, by the aid of a valve amplifier, a circularly rotating ray in a cathode ray tube. This circle forms the time base. The source of wireless frequency oscillations is caused to operate on the ray in such a manner that, in the absence of the large circular movement, a small circular movement of the ray is produced at the wireless frequency. By carefully adjusting the wireless frequency, the light spot in performing its looped journey round the time circle can be caused to arrive at exactly the point from which it started. When this occurs the light spot continually retraces the same path, forming a stationary looped figure. If the two circular motions of the light spot are in the same direction, the ratio of the frequencies is equal to the number of loops minus one.

The setting of the wireless frequency to a known value consists therefore in producing a stationary looped pattern, counting the number of loops and adding one. In the case, for example, of a tuning-fork frequency of 1,000 cycles per second and a number of internal loops of 24, the wireless frequency is exactly 25,000 cycles per second.

Wireless Waves.

By suitable means the time trace can be made a long ellipse. If the wireless displacement is adjusted to be a straight line perpendicular to the long axis of the ellipse, the wave form can be shown and examined.

Apparatus used in this and other exhibits by the National Physical Laboratory in the Wireless group by the following firms :—

Valves, GENERAL ELECTRIC CO., LTD.

Unipivot Galvanometers, CAMBRIDGE INSTRUMENT CO., LTD.

Condensers, DUBILIER CONDENSER CO. (1921), LTD.

Wavemeter, MESSRS. H. TINSLEY AND CO.

DEMONSTRATION.

---

38. *Prof. R. Whiddington. F.R.S.*

Standing Electric Waves on Wires.

Any wireless aerial provides an example of the production of a stationary electric wave, but in the usual case only part of one wave is formed.

The best known arrangement for producing a series of such waves was due to Lecher. A pair of parallel wires were stretched taut and made to oscillate by association with a neighbouring closed circuit excited by spark gap and transformer. The presented arrangement is simply Lecher's system making use of continuous oscillations sustained by valves. The lengths of the wire have been suitably chosen for resonance and the standing waves are detected by bridging across the wires with a small flash lamp. The wave-length is about 1 metre.

DEMONSTRATION.

---

39. *National Physical Laboratory (Dr. R. L. Smith-Rose).*

Wireless Waves.—Directional Effects.

The electric and magnetic fields accompanying a simple wireless wave are at right angles to each other and also perpendicular to the direction of travel of the wave. If, therefore, the direction of both the electric and the magnetic fields can be ascertained, the direction in which the wave is travelling becomes known. In the case of the transmission of waves for short distances over

the earth's surface, the electric field is nearly vertical and the magnetic field nearly horizontal. Making use of these facts the practical types of wireless direction-finders ascertain the direction of the source of transmitted waves by finding the direction of the magnetic field *in a horizontal plane*. **Wireless Waves.**

If a closed coil is placed with its plane vertical in the path of the waves, an electromotive force will be induced therein, the magnitude of which is directly proportional to the sine of the angle between the magnetic field and the plane of the coil. Thus when the coil is parallel to the magnetic field the induced E.M.F. is zero, and when it is perpendicular to the field the resulting E.M.F. is a maximum.

The apparatus demonstrates the principle of such a rotating closed coil direction-finder. On the right is shown a small valve oscillator generating oscillations at a frequency typical of that employed at a modern wireless transmitting station. At the left is a vertical closed coil which can be rotated about a vertical axis. When the coil is set so that its plane is perpendicular to the magnetic field from the oscillator, the current resulting from the E.M.F. induced in the coil causes a movement on the galvanometer used for detecting this current. As the coil is rotated the reading on the galvanometer steadily decreases, until it becomes zero when the coil has been turned through a right angle and its plane is parallel to the magnetic field.

In the practical use of a direction-finder, the magnitude of the current in the coil is indicated by the intensity of the signal heard in telephone receivers. It is then found possible to determine the position of the coil in which the signal passes through its zero intensity much more accurately than the position in which the signal is a maximum. Operating on this principle, such apparatus enables the direction of incoming wireless signals to be determined to within about 1° under the most favourable conditions, and such direction-finders are of considerable use as aids to modern navigation both on sea and in the air.

DEMONSTRATION.

---

40. *National Physical Laboratory (Dr. R. L. Smith-Rose).*

Wireless Waves: Heating Effect.

The heating effect of the currents induced in a coil by a wireless wave is demonstrated by the inclusion of a small glow lamp in the circuit of a small receiving coil. When this coil is placed in the field of the wireless valve oscillator, the resulting current causes the filament of the lamp to be heated. If this current is sufficient the filament becomes incandescent, first, at a red and then at a white heat, the magnitude of the current being approximately indicated by the temperature of the filament.

DEMONSTRATION.

Wireless Waves.

41. *National Physical Laboratory (Dr. R. L. Smith-Rose).*

Wireless Waves: Rectification by Crystals.

The electric and magnetic fields of a wireless wave are of an oscillatory or alternating nature, and the resultant current induced in any wireless receiver is exactly similar. Such alternating currents are unable to cause a deflexion on the simple type of direct current galvanometer. When, however, the receiving circuit includes a crystal detector, the current flowing is partially rectified, and this unidirectional component may be detected by the galvanometer.

In the apparatus shown the presence of the alternating E.M.F. induced in the receiving coil is made known by connecting the coil to a crystal detector and a direct current galvanometer. A deflexion on the galvanometer is obtained, the magnitude of which bears a simple relation to the current received in the coil. When the crystal is short-circuited by a switch, the galvanometer deflexion disappears, due to the inability of the alternating current in the coil to operate this galvanometer.

DEMONSTRATION.

---

42. *National Physical Laboratory (Mr. D. W. Dye).*

Wireless Wave-meter showing Resonance.

The arrangement consists of a simple oscillatory circuit containing an inductance and a variable condenser. The inductance coil of the wave-meter can be coupled to a valve oscillator. When the variable condenser is adjusted to cause the frequency of the circuit of the wave-meter to resonate to that of the source, a large current is induced in the circuit and a considerable voltage occurs at the terminals of the condenser and the inductance.

This condition of resonance may be shown in a variety of ways.

1. Heating of a wire in series in the oscillatory circuit. This may take the following forms: —

(*a*) Hot wire milliammeter.

(*b*) Heater, thermojunction combination and a galvanometer.

(*c*) A small incandescent lamp.

2. The voltage rise on the terminals of the condenser may be shown by the following means:—

(*a*) Electrostatic voltmeter or electrometer.

(*b*) Vacuum tube.

(*c*) Crystal or valve rectifier and galvanometer.

(*d*) A thermionic amplifier and galvanometer.

3. An independent detecting circuit may be used coupled to the inductance coil of the wave-meter circuit. This method possesses several advantages over the other two methods and is to be strongly recommended where possible. The advantages are— **Wireless Waves.**

(i) The damping of the wave-meter can usually be kept smaller and hence the tuning is sharper.

(ii) Freedom to choose the proportions of the independent circuit to suit the detecting device used.

(iii) The detecting device may be changed from one kind to another to suit requirements or the convenience of what is available without altering the calibration of the wave-meter.

The disadvantage of the method is that slightly more energy is consumed from the source for a given detector when this detector is that best suited to the wave-meter when used in methods 1 or 2. This, however, is of small consequence in most cases.

DEMONSTRATION.

43. *National Physical Laboratory (Mr. D. W. Dye).*

Delineation of Damped Radio Waves.

If a resonant electric circuit has a current suddenly started in it and is then left free to oscillate, the resulting oscillations will gradually die down to zero. There may be only a few oscillations or there may be a few hundred before they are reduced sensibly to zero. The rate at which the decay of amplitude occurs depends upon the resistance of the circuit in relation to the inductance and the capacity. Examples of damped oscillations are those provided by spark and buzzer excitation of a circuit. These methods, however, whilst very commonly used in practice, are not sufficiently steady to show on the screen of an oscillograph, where it is necessary to repeat several hundred successive trains of such oscillations at exactly equal intervals of time.

In order to show the oscillations satisfactorily on the elliptical time trace given by the oscillograph, it is necessary to give impacts or electrical blows to the oscillating circuit at such a rate as to be equal to a multiple of the frequency of the tuning-fork providing the time trace. The tuning-fork itself cannot be used directly to deliver the electrical blow to the oscillatory circuit, since the former has a current wave which is smooth and free from discontinuities.

An arrangement known as a multi-vibrator is therefore employed. The action of this is somewhat complicated and difficult to follow and will not be described here. It will suffice to state that it supplies to an inducing coil a small current, the wave form of which possesses an almost perfect discontinuity. The current changes almost instantaneously from one value to another, thus producing what amounts to an electrical blow in the resonant circuit coupled to the inducing coil. The rate at which the blows are produced can be varied within wide limits by adjustment of the variable condensers of the multi-vibrator.

Wireless Waves.

In the present arrangement the frequency of the multi-vibrator is adjusted to 1,000 cycles per second, and this frequency is held exactly constant by the help of a small voltage obtained from the tuning-fork. The multi-vibrator delivers two electrical blows to the oscillatory circuit at each alternation of its operation. There will therefore be two trains of damped oscillations started in the oscillatory circuit at each revolution of the light spot of the cathode-ray tube. Each of the two damped trains of waves will commence at an invariable point on the time trace. The resulting wave traces will therefore remain stationary on the screen.

If the multi-vibrator is freed from the control of the tuning-fork, and is then adjusted in frequency to be very slightly different from that of the fork, the resulting trains of damped waves will progress or retrogress round the ellipse. The peculiar phenomena occurring in two coupled resonant circuits of slightly different frequencies can also be well shown.

DEMONSTRATION.

---

44. *National Physical Laboratory (Mr. D. W. Dye).*

Interference between Two Radio Frequency Waves.

The cathode ray tube is arranged to show wave form at radio frequency. (*See* Exhibit 37.)

Two wave forms from two independent valve oscillators are simultaneously projected upon the screen of the oscillograph. If the two frequencies are adjusted so that each is an integral multiple of the tuning-fork frequency, they will interfere with a difference frequency which is also an integral multiple of the fork frequency. The pattern produced will therefore be stationary and hence visible. By making the amplitudes of the two waves equal, the combined wave will swell up to a maximum and then die down to zero as the waves first reinforce and then oppose one another. If the two waves are unequal, there is a swelling-up and dying-down of the wave of a kind very similar to that produced by modulation at the frequency equal to the difference between the two radio frequencies.

DEMONSTRATION.

---

45. *Research Laboratories of the General Electric Company, Ltd.*

Anode of Valves Red Hot by Bombardment of Electrons.

Bombardment of the anode of a two-electrode valve by electrons is shown. The number of electrons can be controlled by the filament temperature.

Two valves are shown, the first a valve of normal design with nickel anode, the second with an anode consisting of a disc of tungsten which can be heated to much higher temperatures than the nickel anode.

DEMONSTRATION.

46. *Research Laboratories of the General Electric Company, Ltd.*

Change in Temperature Distribution along an Emitting Filament (Illustration of Thermionic Emission).

A long thin filament surrounded by an anode of grid form. The filament is heated by direct current and is normally of uniform temperature. When a D.C. voltage is applied between filament and anode, and an emission current is taken from the filament, the temperature at the negative end increases visibly and at the positive end decreases.

DEMONSTRATION.

---

47. *Research Laboratories of the General Electric Company, Ltd.*

A Method of Reducing Temperature Change resulting from Thermionic Emission.

The effect shown in Exhibit 46 may have serious consequences on the life of a filament.

A rectifier is shown rectifying alternating current and the filament is heated from the same source, but the phase of the filament current can be changed by means of a phase-shifting transformer. When the filament current is in phase with the anode volts, one end of the filament is always negative when emission current is flowing and consequently is overheated. When the phase is shifted 90° this overheating disappears, for now each end of the filament is equally negative and positive when the emission current is flowing. On shifting the phase another 90° the other end of the filament becomes overheated.

DEMONSTRATION.

---

48. *Research Laboratories of the General Electric Company, Ltd.*

Wehnelt Cathode (Illustration of Thermionic Emission).

(*a*) The thermionic valve depends on the fact that at high temperatures electrons are emitted from all substances. A tungsten filament is shown mounted in vacuum surrounded by a metal anode. A high voltage is applied between the filament and anode sufficient to drag across all electrons emitted from the cathode.

The electron current to the anode is indicated by a milliammeter and its variation with filament temperature can be observed.

(*b*) A modern development of the original Wehnelt cathode is shown. A cylinder of nickel, coated with mixed oxides of the alkaline earths, is heated to a dull red by radiation from an enclosed tungsten filament.

DEMONSTRATION.

Wireless Waves.

49. *Research Laboratories of the General Electric Company, Ltd.*

Characteristic of Valve.

The static characteristic of a three electrode valve is shown by means of a cathode ray oscillograph. The filament current can be varied and the consequent changes of characteristic observed.

DEMONSTRATION.

---

50. *Dr. J. A. Fleming, F.R.S.*

The Origin and Development of the Thermionic Valve in Wireless Telegraphy and Telephony.

The thermionic valve has been developed in the last twenty years by the work of numerous inventors out of a pioneer invention made in 1904 by Fleming, which was the first technical application of purely scientific researches on the emission of negative electricity from hot bodies. The thermionic valve has given us the most sensitive appliance yet discovered for the detection of electric waves and also one of great utility for generating the waves used in wireless telegraphy and telephony.

It consists essentially of a form of incandescent electric lamp in which a wire of some material, generally tungsten, is rendered incandescent by an electric current, this wire being enclosed in a glass or silica bulb from which the air is most completely exhausted. Around the filament is fixed a cylinder of metal called the anode, which is connected to the wire sealed through the bulb wall. When the filament is hot it emits torrents of electrons or particles of negative electricity, and these are caught on the anode. In this simple form it is called a "rectifying valve" because it has the property of permitting (negative) electricity to be conveyed only in one direction through the vacuous space from filament to anode. Hence it is used to convert alternating or oscillating electric currents into direct or unidirectional currents. It was first introduced in this form as a rectifier and detector of the feeble electric oscillations in the receiving circuit of a wireless telegraph apparatus. It is now manufactured in very large sizes, as shown in the exhibit, for the purpose of rectifying large electric currents.

An improvement was made in it in 1907 by Lee de Forest by the introduction of a grid or zig-zag of wire between the anode and filament. This grid now takes the form of a spiral of wire or a cylinder of metallic gauze. In this so-called three-electrode form, the valve can be used to amplify or magnify electric currents and also to generate electric oscillations. Samples of large generating valves are shown in the exhibit.

Another important improvement was the introduction of metallic thorium into the filament, which enables it to give a larger electron emission at a dull red heat. These dull-emitter valves are now used as receiving valves and are made in very small sizes.

The exhibit comprises examples of modern two-electrode (Fleming) or rectifying valves, of three-electrode generating and amplifying valves and of dull emitter detecting valves made and contributed by the M.O. VALVE CO., LTD., THE MULLARD RADIO VALVE CO., LTD., the EDISON SWAN ELECTRIC CO., LTD., and the BRITISH THOMSON-HOUSTON CO., LTD. It includes also speciments of Fleming's original rectifying valves, which are the progenitors of all the rest. **Wireless Waves.**

---

51. *Prof. R. Whiddington, F.R.S.*

The Ultra-micrometer. A New Electrical Device for Minute Measurement.

The ultra-micrometer was devised in 1919-20 (*Philosophical Magazine*, 1920), and represents one of the many possible applications of the thermionic valve to physical measurement.

The principle involved is extremely simple. When the distance between the plates of a parallel plate condenser is slightly altered its capacity changes in a way readily calculable, the capacity change being the greater the closer the plates. This change can be indicated in a variety of ways, but in the present case is observed by noting the change in frequency of the high frequency oscillations maintained by a three-electrode valve in an inductance circuit containing the condenser.

In the particular apparatus exhibited, the condenser is linked to a spherical ball bearing, so that variations of the diameter of the ball in different directions may be observed. A null method is employed, so that by restoration of the original frequency of oscillation the diameter variation may be computed. The manner in which the restoration is here effected is to apply a small bending moment to the stiff bar carrying the movable condenser plate by depressing one end of another much lighter bar through an observed amount. From the observed depression required to restore the original frequency the diameter change can be calculated.

While the instrument shown is intended only to indicate changes of about one-tenth millionth of an inch, it has been found possible under favourable conditions, with an apparatus of different design, to detect changes of so little as 1/200 millionth of an inch.

DEMONSTRATION.

SLOW OSCILLATIONS.

52. *National Physical Laboratory (Mr. D. W. Dye).* **Slow Oscillations.**

Slow Oscillations.

The apparatus exhibited consists of (*a*) a generator of electric currents of audio-frequency by means of a triode valve, and (*b*) a resonant circuit and various indicating devices. Current from this

Slow Oscillations.

source flows through an inductive coil. The magnetic field produced by the coil can be used to demonstrate various phenomena as follows :—

(A) Resonance and Selective Absorption.

The coil of the generator induces into a resonant circuit consisting of an inductance coil to the terminals of which a condenser is connected. When the condenser is adjusted to that value at which $4\pi^2n^2LC = 1$, where n is the frequency of the oscillation and L is the value of the inductance, a large resonant current occurs in the circuit. This condition of resonance may be demonstrated by various means.

If the current wave in the inducing coil of the oscillator possesses harmonics, the resonant circuit will only respond to that component of the wave to which it is tuned and so selectively absorbs energy of this frequency. The frequency may be that of the fundamental or it may be any one of the harmonics.

(B) Heating Effects.

A small lamp connected to a coil of a few turns of wire can be caused to glow when brought near the inducing coil of the oscillator.

(C) Directive Effects.

When the coil and attached lamp or a telephone are turned so that the plane of the coil is in a position of zero mutual inductance with respect to the inducing coil, no electro-motive force will be induced therein and the lamp will not glow. When a telephone is used as an indicator of this condition, the position of zero mutual inductance can be observed with great precision.

(D) Acoustical Effects.

When a coil having a telephone receiver connected to its terminals is brought near the inducing coil of the generator, a loud sound results. The pitch and character of this sound depend upon the frequency and wave-form of the current traversing the inducing coil.

When the current is of a sinusoidal wave-form, the note produced is a pure tone, but when harmonics are present in the source of current the note assumes a character which can be approximated to various sounds. The presence of numerous high harmonics or overtones gives the sound a strident character.

By the use of a second independent audio-frequency generator, various combined musical notes may be produced such as the octave, major and minor third, fourth, fifth, sixth, etc. These are produced by inducing currents from each source into the telephone and adjusting the frequencies so that the ratio of them is a simple fraction such as 2 : 1 for the octave, 3 : 2 for the major fifth, etc. When the two frequencies are adjusted to be nearly equal the phenomena of beats is observed. If the intensities of the currents from the two sources are made equal, the sound produced falls to silence and swells up again in a slow rhythmic manner.

These effects may be shown visually by means of the Low-Hilger audiometer, which can conveniently be used to measure the frequency and show the wave-shape of sounds produced either by the telephone as used in the above experiments or by speaking, singing, etc., in front of the trumpet of the instrument. **Slow Oscillations.**

Audio-frequency oscillators by MESSRS. H. W. SULLIVAN, LTD.; Low-Hilger Audiometer by MESSRS. ADAM HILGER, LTD.; Condensers by MESSRS. H. TINSLEY & CO.; Loud speaker by MESSRS. S. G. BROWN, LTD.

DEMONSTRATION.

---

53. *Research Laboratories of the General Electric Company, Ltd.*

Thermionic Rectifier.

An experimental type of high power thermionic rectifier for use on a 30,000*v.* supply is shown. The anode is of copper and is cooled by circulating water through the water jacket (shown separately). The electron emission from the filament is more than five amperes.

---

54. *Research Laboratories of the General Electric Company, Ltd.*

Conversion of Alternating Current to Direct Current by Means of the Thermionic Rectifier.

The cathode ray oscillograph shows an alternating current passing through a resistance. A thermionic rectifier is then inserted in the circuit and the suppression of half the wave is shown. A smoothing network of condensers and inductances is then inserted in addition and almost steady direct current obtained.

DEMONSTRATION.

GEOPHYSICS.

101. *Sir Napier Shaw, F.R.S.* **Geophysics.**

Solar and Terrestrial Radiation.

Among the natural effects of radiation with wave-length between one ten-thousandth and a few hundredths of a millimetre may be classed the whole sequence of weather. The ultimate sources of all atmospheric disturbances are solar and terrestrial radiation, the effects of both of which are largely contingent upon the condition of the atmosphere in regard to radiation and absorption.

Geophysics.

Included in the exhibits are therefore, first, a diagram illustrating the distribution of energy according to wave-length in a beam of sunlight outside the atmosphere, and in the long wave radiation from a black body at a temperature of 287*t*.

Secondly, a map showing the positions of stations where solar radiation has been measured and the results obtained.

Thirdly, a map showing the rate at which energy would escape by radiation through transparent atmosphere from black bodies in different parts of the world according to the mean temperature of the air at the surface in the month of July.

Fourthly, instruments designed by Prof. H. L. Callendar, C.B.E., F.R.S., to measure direct solar radiation and sky radiation, and an instrument designed by Mr. W. H. Dines, F.R.S., to compare the radiation from the sky with that from a grass meadow.

Fifthly, a table of the results of observations of radiation obtained in England, day by day, during 1924, with summaries for weeks and for the quarters of the "May Year."

---

102. *Sir Napier Shaw, F.R.S.*

Meteorology: the General Circulation of the Atmosphere and its Local Disturbances.

The direct expression of solar and terrestrial radiation is the general circulation of the atmosphere with its local disturbances of a transient character, the study of which constitutes the science of meteorology. Chief among the results of the general circulation of the atmosphere is the supply of water, the most important of all considerations of the well-being of any community. Nearly all parts of the habitable world are dependent upon rainfall; a few only depend entirely upon irrigation. Evaporation, on the other hand, takes away vast quantities of water from plants, soil, rivers and lakes. This perpetual conflict is illustrated by two maps of the world, one showing the normal amount of rainfall in the year and the other showing the loss of water by evaporation; both are expressed in millimetres of water.

The contrast between the effectiveness of the methods of observation of the two elements respectively is brought out by the irregularities of the measures of evaporation as compared with the orderly lines obtained from readings of the rain-gauge. The proper form of gauge for evaporation and the proper exposure have still to be found. Illustrations of the form which is most approved in this country and of other forms used elsewhere are associated with the maps.

The exhibit, which is designed to illustrate the dynamical processes of the general circulation and its changes, starts from barometers and thermometers for use at ground-level stations. Thence it leads by way of special instruments adapted to measure the temperature and pressure in the upper atmosphere even at such great heights as 20 kilometres, or 12 miles, up to a representation of the general circulation of the atmosphere derived from the co-ordination of the results obtained.

The representation includes, first, a model of the distribution of temperature at different levels, with the mode of incorporation of cyclones and anti-cyclones in the general circulation. Secondly, a scheme of normal distribution of pressure and associated winds at heights of 4 kilometres, 6 kilometres, and 10 kilometres set out as isobaric lines on concentric hemispherical globes. Geostrophic scales are exhibited by which the wind velocity corresponding with the distribution of pressure can be ascertained, and a rough drawing of the circumpolar circulation derived from the measurements with the scales, or from numerical calculation.

The local disturbances, which are common in temperate latitudes as cyclonic depressions in a great variety of forms, are presented in the examination and analysis of a particular depression of September 10th, 1903, by which the apparent complication of the record of an anemometer, after making allowance for the friction of the ground, is traced to the combined motion of spinning, according to a certain law, and travelling at the same time with an ascertained velocity.

The complexity of local disturbances, including the winds, disclosed by observations of pilot-balloons, is represented in five models composed of glass-plates, two for Great Britain, one for Bermuda, one for Jamaica, together with one which suggests the gradual changes from a N.E. wind near the surface to a S.W. wind at 1,500 metres.

A collection of diagrams illustrates the thermal and dynamical effects of the heat which we derive from the sun, and the actual conditions of air shown by the observations of temperature at successive heights in relation to the properties of air elicited by physical experiments and mathematical study. Special forms of diagram for eliciting these relations are displayed from which the energy of saturated air or of dry air in an environment defined by observation can be estimated. The eventual outcome of the arrangement is an "indicator-diagram" for the atmosphere, regarded as a steam-engine.

All the instruments are graduated systematically and the diagrams are adjusted in close relation with the C.G.S. system.

The apparatus for the "sounding" of the upper air is from designs by Mr. W. H. Dines, F.R.S. The millibar barometers, thermometers for air and earth and the dial gauge for evaporation are by MESSRS. NEGRETTI & ZAMBRA; the special logarithmic paper and scales by MESSRS. W. F. STANLEY & CO., LTD.

---

103. *Capt. C. J. P. Cave.*

Cloud Photographs.

The collection of cloud photographs is designed to show certain typical cloud formations. Upper clouds are represented by various forms of cirrus, clouds varying much in appearance; cirro-cumulus and alto-cumulus ordinarily have either waved or tessellated structure. Some of the photographs in the collection showing cloud

Geophysics.

structure indicate the rapid way changes take place in the finer structure of upper clouds. At all levels, clouds may show a lenticular shape; examples are given from cirro-cumulus at great heights to strato-cumulus in the lower levels of the atmosphere. The upper lenticular clouds are often wavy at the edges. The tendency of clouds to be arranged in bands is very evident in the upper clouds, but examples are given of cumulus arranged in parallel lines, and of the extreme case of roll-cumulus. In the same collection with low clouds will be found examples of fogs. In the same frame is a photograph of the whole sky on one plate taken with a special lens.

Photographs of clouds taken from aeroplanes are mostly of low clouds of the strato-cumulus variety, the upper surfaces of which resemble the tops of fogs as seen from hills; one remarkable example shows a cumulus cloud rising through a level sheet of cloud. Examples of cumulus clouds show small clouds of this type as well as the towering clouds with false cirrus at the top, which mark showers and thunderstorms. With these is a photograph of a rainbow, showing supernumerary bows and the outer bow, and the darkness of the sky outside the primary. A few examples of lightning are given, showing also the spectrum of lightning, and the way flashes follow each other in nearly identical paths, as revealed by photographs taken with a moving camera.

Diagrams are shown in which the heights of different forms of cloud are indicated; these are mean heights as observed in England; the actual heights vary very much.

104. *Dr. C. Chree, F.R.S., and Mr. C. S. Wright.*

Terrestrial Magnetism.

As a principal object of the exhibition is to show the advance of science, a brief reference is needed to the state of our knowledge 30 years ago. The increased amplitude of the regular diurnal variation of the magnetic elements with increase of sunspots, discovered towards the middle of last century, was generally accepted by magneticians, who also generally believed in a tendency to an increased number of large disturbances—*i.e.*, so-called magnetic storms—near sunspot maximum. A claim that magnetic storms tended to recur after an interval corresponding to the sun's rotation—a phenomenon suggestive of direct solar action—had been advanced by Broun, but had passed into oblivion. On the other hand, Lord Kelvin had demonstrated—it was thought conclusively by all who assumed that the sun must act, if at all, as a distant magnet—that for the sun to produce a magnetic storm on the earth was a physical impossibility. It was supposed that irregular phenomena such as magnetic storms, and the regular diurnal changes such as the usual swing to the west of the compass needle in the forenoon, were quite independent. While recognising that their assumptions were hypothetical, Rücker and Thorpe, in reducing the field observations for their great magnetic survey for the epoch 1891, assumed that the regular diurnal variation, when referred to local time,

was identical for all places in Britain, and was the same on quiet and disturbed days, and that superposed on this were disturbances, which at any instant were the same all over the British Isles. **Geophysics.**

A series of Kew curves, declination (D), horizontal force (H) and vertical force (V) for 1894, a highly disturbed year, illustrate the usual phenomena of magnetic storms. Of the four storms selected three had "sudden commencements" (Sc's.). An Sc. is not instantaneous, but occupies several minutes. It is specially prominent in H where it normally consists of a rise (movement up the sheet), sometimes preceded by a small rapid fall. The large movements may follow the Sc. immediately, or only after several hours. Sc's. occur simultaneously, or very nearly so, all over the world. During a magnetic storm the D and H traces may have several large oscillations on both sides of the normal, but as a general rule H is finally left depressed. The shape of the V trace is more dependent on the time of day. In almost every storm the trace has a humped appearance (force above normal) in the afternoon, a cup appearance (depression) in the early morning, but one of these features may be lacking if the storm is a short one.

A storm larger than any experienced in 1894 --possibly the largest storm of the last fifty years—occurred in May, 1921. It lasted for several days. Its most disturbed part is represented by Kew D, H and V traces. The very rapid oscillations shown during the day on all the Kew V traces are mainly due to disturbance from the local electric railways. Fortunately, the largest natural movements occurred in the night hours when trains were not running.

The points of agreement and difference between simultaneous magnetic disturbance in different parts of Britain are illustrated by copies of declination curves obtained in 1923 from three or more of the following places: Kew, bottom and surface of Sandwell Park Colliery near Birmingham, Eskdalemuir and Lerwick. The ordinate scale was only about half as open at Lerwick as at the other stations. Corresponding points, distinguished by letters, are easily recognised, especially at the more southern stations. But the amplitude of the movements, instead of being uniform, as Rücker and Thorpe supposed, increases rather rapidly as we go north. This, it may be added, seems almost invariably the case in Britain.

The tendency for a series of magnetic storms to follow at intervals of about twenty-seven days, which Broun had observed, was rediscovered independently from a study of Greenwich curves by Mr. W. Maunder, who supposed the cause to be a jet-like discharge of some kind from a sunspot area, the repetitions arising from the persistence of the sunspot for several solar revolutions. According to modern physical theories such as that of Birkeland, the discharge takes the form of ions emanating from the sun.

Of interest in this connexion is the diagram from Greenwich Observatory, showing for an 11-year period the distribution of sunspots in latitude, and their comparative number, together with the mean areas of sunspots, and the variation which proceeds *pari passu* in the amplitude of the diurnal range of the magnetic declination.

Geophysics.

Views analogous to Mr. Maunder's led the late Father A. L. Cortie, of Stonyhurst, to connect individual storms with individual sun-spots, and to trace their contemporaneous development. His views and investigations are illustrated in a large frame, which shows the Stonyhurst records of a number of storms with the state of the sun's surface at the time.

The 27-day interval is not confined to magnetic storms. It can be traced even in quiet conditions. There is, in short, a very sensible correlation between the magnetic character, whether disturbed or quiet, of two days which are twenty-seven days apart. This is illustrated by a number of diagrams in which the magnetic state of the day is measured by the international character figure assigned at De Bilt, or by the daily range of one of the magnetic elements. One of the diagrams shows that the 27-day interval also manifested itself in the auroras recorded in 1911 by the Scott Antarctic Expedition. There is not, as yet, universal agreement as to the precise nature of the connexion between the sun and the magnetic phenomena on the earth, but the views entertained prior to Lord Kelvin's criticisms are again in the ascendant.

At ordinary stations, while small magnetic disturbances are the rule rather than the exception, large disturbances are rare, and when they occur, they are large everywhere, and usually last for a number of hours. Also there are many days, especially in years with few sunspots, free from any but trifling irregularities. But in high magnetic latitudes really quiet conditions are very rare, and there are often active disturbances lasting for an hour or two which are represented only by comparatively trifling disturbances in low latitudes. This phenomenon is illustrated by copies of simultaneous records obtained during 1911 and 1912 at the base station of the Scott Antarctic Expedition and at various observatories, ranging from Mauritius in the south to Sitka (Alaska) in the north. After making due allowance for the greater sensitiveness of the magnetographs at some of the stations, *e.g.*, Buitenzorg, in Java, it was found that these short disturbances tended to be simultaneously large in the Antarctic and the Arctic, while comparatively small near the equator.

With the object of following more minutely the sequence in time of magnetic changes, arrangements were made in connexion with recent Antarctic Expeditions for obtaining "quick run" curves with a very open time scale on certain occasions. These are obtained by rotating the drum on which the photographic paper is wound at a much higher rate than usual. Examples of quick run curves with interesting magnetic changes are shown.

During 1912 expeditions led by the late Captain Scott and by Sir Douglas Mawson had magnetographs running simultaneously at stations on opposite sides of the south magnetic pole. Diagrams show the diurnal variations of the magnetic elements at the two stations. These can be interpreted as oscillations in the position of the magnetic pole, V rising and H falling as the pole moves towards a station. In this way, two independent estimates were formed of the average daily motion of the magnetic pole for groups of days, the different groups representing different degrees of magnetic disturbance. The large increase in the calculated daily

travel of the magnetic pole, as we pass from the very quiet to the less quiet days, is conspicuous. This shows how wide of the mark was the view that the regular diurnal variation is independent of disturbance. But the influence of disturbance on the regular diurnal variation is much larger in the Antarctic than in Britain. **Geophysics.**

The magnetic elements are in a continual state of change. The changes of declination and inclination in the London area have been observed at one station or another for nearly 350 years. They are jointly illustrated in a diagram, declination east and west being measured in the horizontal direction, and inclination in the vertical direction. When first observed, the compass needle in London pointed to the east of north. Gradually it pointed more and more westerly, until about 1818, when it pointed 24½° west of north. Since then westerly declination has steadily declined. Inclination when first observed was nearly 5° greater than it now is, and it increased to a maximum about 200 years ago. Thereafter it declined steadily until a few years ago. Of late years it has been nearly stationary.

Another diagram shows declination changes separately. The more recent years' results, which are derived from Kew, are shown in more detail. The change has accelerated of late years and is now at the rate of about 1′ per month, a rate which was not approached during the nineteenth century.

---

105. *Dr. C. Chree, F.R.S., and Mr. C. S. Wright.*

Atmospheric Electricity.

The phenomena of atmospheric electricity vary greatly according to the weather. In fine weather electric potential as a rule is higher in the air than on the earth—*i.e.*, the potential gradient is positive. During rain, the potential gradient usually alternates between positive and negative. During a thunderstorm, every lightning flash is accompanied by a large sudden change of potential. During fog—especially dirty fog—potential gradient at Kew is usually very high.

A series of corresponding Greenwich and Kew electrograms shows the extent to which the phenomena agree at comparatively near stations. During the great thunderstorm of July 9–10, 1923, lightning was almost incessant for several hours in the London area, and the movements of the light spot across the photographic paper were often too fast to leave a clear trace.

Eskdalemuir, in Dumfriesshire, is so distant that the weather there usually differs considerably from that at Kew. Thus no comparison is made between simultaneous Kew and Eskdalemuir electrograms, but traces are shown representative of corresponding weather conditions.

The Eskdalemuir electrograph is less sensitive and uses a wider photographic sheet than the instrument at Kew; but even the Eskdalemuir trace is incapable of showing changes of more than a few thousand volts per metre in the potential gradient, and

Geophysics.

thus cannot show the true nature of the enormous and extremely rapid changes of potential which occur when a lightning flash occurs within a few miles. The apparatus of Prof. C. T. R. Wilson, of which a photograph is exhibited, is designed for this purpose, and copies of some of the records obtained with it are also shown.

In the electrograms representative of fine weather, a more or less regular diurnal variation of potential is recognisable. To show its real nature, it is necessary to combine hourly measurements from a number of days. The diurnal variations thus resulting at Kew and Eskdalemuir are illustrated by diagrams. The variations are shown separately for the midwinter months (November to February) combined, and the midsummer months (May to August) combined, as well as for the whole year. The Kew type of diurnal variation has a well-marked double oscillation, with maxima in the evening and in the late morning hours, and minima in the early morning and early afternoon. At Eskdalemuir a double daily oscillation is fairly recognisable in winter, but in summer only a vestige of it is left.

The diurnal variation of potential gradient at Kew is compared in another diagram with that of atmospheric pollution, as measured by Dr. Owens' pollution recorder, which functions near the electrograph. There is a close general resemblance between the two diurnal variations. There is much less dirt in the air in summer than in winter, and the potential gradient is also much lower in the former season than in the latter. As, however, one of the diagrams shows, the annual variation of potential gradient is little, if at all, more conspicuous at Kew than it is at Eskdalemuir, in the open country.

Amongst other important atmospheric electricity elements are the ions—positive and negative—always present in the atmosphere, and the (small) vertical electrical current, always passing between the upper atmosphere and the earth. Diagrams are exhibited showing the annual variation of these elements at Kew.

---

106. *Prof. H. H. Turner, F.R.S., and Mr. J. J. Shaw.*

Seismology.

(A) The Milne-Shaw Seismograph.

This is a new type of earthquake recorder with high magnification and electro-magnetic damping. The magnification is approximately forty times greater than in the standard Milne instrument, while in practice the sensitivity to tilt is from ten to twenty times greater, according to the pendulum period adopted.

The general principle of the apparatus is to multiply the movements of a short horizontal pendulum by reflecting a beam of light from a pivoted lens of half-metre focus. The pendulum carries a weight of 1 lb. together with an electrolytic copper damping vane, floating between the poles of four tungsten steel magnets, whereby any degree of damping is obtained and the pendulum brought to

rest after each excursion. The outer end of the boom is coupled to and rotates the mirror; by this means 500 multiplications of the motion may be readily obtained, but in practice 150 to 250 are found to be more suitable.

Special calibrating and adjusting devices were necessary with such high magnification. This point has received special attention; tilts of 1/100 of a second of arc (one inch in 300 miles) can be applied and registered by the image of a spider line on a distant scale. All such operations are performed and the scales read at a distance from the pendulum, so that there are no movements of the observer to confuse the issue. Adjustments to the recording light-spot are made by means of a long flexible cable, and artificial deflexions for testing purposes by a solenoid.

The record is timed by an electromagnetic shutter contained within the lamp, which may be illuminated by electric current, gas or oil.

The "Milne-Shaw" seismograph is particularly suited for measuring not only earthquake movement, but also small changes of level, such as deflexion of the coast due to tidal load.

Pendulum periods of 60 to 90 seconds can easily be obtained. When set up to 90 seconds, with a multiplying ratio 250 : 1, a deflexion of 1 mm. of the light spot is produced by so small a tilt as 1 inch in 8,000 miles, or 0·0004 seconds of arc.

Arrangements have been made for showing the seismograph in operation.

DEMONSTRATION. The instrument is housed in a separate chamber and may be seen on application to a demonstrator.

(B) Seismological Maps.

Maps of the world are exhibited (*a*) showing the position of stations possessing seismographs which send records to headquarters (at Oxford), or have done so in times past (*e.g.*, those in Russia); and (*b*) showing localities where earthquakes have occurred in the years 1913-1919, as determined at Shide or Oxford. These earthquake centres will be seen to lie upon two or three well-defined lines on the earth's surface, which have some interesting geographical relationships. A set of publications giving details of earthquake records 1913-1919 is also exhibited.

(C) The Location of Earthquake Centres.

A globe used by Prof. Milne for determining the position of earthquake centres by measurement of distances from the observing stations is exhibited, and, if possible, another globe of more modern construction, showing the great increase in number of observing stations since Milne's time.

ZOOLOGY.

Zoology.

201. *Prof. E. B. Poulton, F.R.S.*

Mimicry in an African Swallowtail Butterfly.

The females of an African Swallowtail Butterfly, *Papilio dardanus*, provide the most interesting and elaborate example of mimicry yet known.

In Madagascar, the Comoro Islands, Abyssinia and Somaliland, this species is represented by closely allied forms in which both sexes are alike and non-mimetic. In other localities on the mainland of Africa the females of *Papilio dardanus* mimic butterflies of a very different group, the Danainae ; in these both sexes are alike, they are unpalatable, and they are mimicked wherever they occur by other butterflies and by moths.

Three different forms of female of *Papilio dardanus* mimic three very distinct Danaine patterns ; two of these patterns are modified in passing from one area to another, and in the same regions the mimetic females are correspondingly altered to match them. In Uganda and West Africa a fourth form of female of *Papilio dardanus* occurs ; this mimics an entirely different pattern, that of two species of the Acraeinae, a group of unpalatable butterflies remote from the Danainae, but like them mimicked in various parts of the world.

Most swallowtail butterflies have long "tails" to the hind wings. These are present in the male of *Papilio dardanus*, but the mimicking female forms of this species have become tailless, like their "models." Vestiges of tails occur, however, in some transitional females, and occasionally in the mimetic form that has the most primitive pattern, that is, the one most like the male pattern. Pockets for the tails are found in the female chrysalis, but tails are not developed in them.

In the exhibit the Danaine and Acraeine "models" may be distinguished by their red-printed labels and by their position above their mimics.

The arrangement is geographical. Non-mimetic forms from Madagascar and Somaliland are followed by primitive females from Nairobi, exhibiting some of the steps by which the mimetic forms arose. Then come the fully formed mimics with their models, first along the east coast of Africa from north to south, next Uganda, where all four mimetic females and their models occur together, finally the west coast. The map shows the localities in which the specimens were taken.

Experimental breeding has shown that all the mimetic forms may be bred from females of the same or of a different form, and that the same brood may contain two or three different mimics, as well as the non-mimetic males.

202. British Museum (Natural History): Dr. C. J. Gahan. Zoology.

Mimicry in Beetles.

(i) *The Lycidae and their Mimics.*

The beetles of the family Lycidae are conspicuously coloured, fly slowly, and secrete distasteful liquids. They show little diversity in form and, in the same region, but little in colour, most of the Asiatic species being red and the South American ones black and yellow. Thus they are easily recognized and it is established that they are singularly free from the attacks of insectivorous animals. Wherever they occur they are mimicked by day-flying beetles of other families, and sometimes also by day-flying moths and other insects. It is of interest to note that mimicry is unknown in beetles that fly by night; as a rule these have a coloration that harmonizes with the object—ground, tree trunk, or leaf, etc.—on which they rest during the day.

(ii) *The Cerambycidae and their Models.*

The beetles of the family Cerambycidae are not protected by a distasteful secretion. Many of them look quite unlike their nearest allies, but show a close resemblance in form, size and coloration to unrelated insects, either noxious beetles of other families, or stinging insects such as wasps. The diversity of this family, when contrasted with the uniformity of the Lycidae, is most striking.

203. British Museum (Natural History).

Biological Results of the "Terra Nova" Expedition.

The "Terra Nova" Expedition (1910-1913), under the command of the late Captain R. F. Scott, R.N., C.V.O., was thoroughly equipped for scientific work in both men and material. On the outward and homeward voyages from England to New Zealand, fine meshed tow-nets were put overboard whenever possible, and hauls with the trawl were made off Rio Janeiro and near the Falklands. In the winter cruise (July to October, 1911) to the north of New Zealand, hauls made with trawl and dredge at depths of 15 to 300 fathoms revealed a bottom-fauna of extraordinary variety, including a great number of forms new to science. Samples of plankton and of muds and oozes were obtained between New Zealand and McMurdo Sound, and the results of trawling in the Ross Sea much increased our knowledge of the Antarctic marine fauna. The work on shore included the study of birds and of parasitic worms; especially notable was the hazardous winter journey to Cape Crozier, to secure eggs with early embryos of the Emperor penguin.

The exhibit includes charts showing the stations where specimens were obtained either by tow-netting or by trawling, and a selected set of the scientific reports in which the collections are described.

Zoology.

204. *British Museum (Natural History): Mr. C. Tate Regan, F.R.S.*

Evolution in Fishes.

(A) The Protractile Mouth of Epibulus.

Cheilinus and *Epibulus* are two genera of Wrasses from the tropical Indo-Pacific; they are closely related, agreeing in form, scaling, structure of the fins, dentition, etc. *Cheilinus* has the mouth moderately protractile, but in *Epibulus* it is extremely protractile. There can be no doubt that the remarkable structural modifications connected with the great protractility of the mouth in *Epibulus* have been derived from the normal arrangement found in *Cheilinus*. It is of great interest that this marked adaptive change has taken place whilst the fish has remained a *Cheilinus* in other characters. It is probable that *Epibulus* has evolved from a *Cheilinus* that formed the habit of catching its prey by a sudden protrusion of the mouth.

(B) The Killarney Shad (*Alosa finta killarnesis*).

The Twaite Shad (*Alosa finta*) of the Atlantic coast of Europe enters rivers in the spring to breed; the young fish remain about a year in the rivers or estuaries and then make for the sea, first returning to breed when they are about a foot long. In Killarney there is a Shad which lives in the lakes throughout its life and differs from the Twaite Shad only in its smaller size (maximum length about 9 in.), deeper body and more numerous gill-rakers. The Killarney Shad has evidently evolved from the Twaite Shad, young of which remained in the lakes instead of going to the sea, and founded a lacustrine colony. The increased number of gill-rakers in the Killarney Shad is doubtless related to a life-long diet of minute Crustacea; these form the sustenance of the Twaite Shad during the first year of its life, but in the sea it feeds on larger Crustacea, small fishes, etc.

---

205. *British Museum (Natural History): Dr. W. D. Lang.*

Continuous Evolution, with Recapitulation, in Carboniferous Corals.

In corals the polyp—an animal very similar to a sea-anemone—is attached to the inside of a cup-like structure formed of the hard coral substance; the inner surface of this cup bears a number of ridges—the septa—that project inwards towards the centre

The diagrams exhibited represent enlarged transverse sections of the "cup" of some simple corals found in the Carboniferous Limestone of Scotland, studied by Mr. R. G. Carruthers. The five different forms represented are found in five successive horizons, and it is inferred that each is the direct descendant of the earlier one below it. It will be seen that the septa, which at

first meet in the middle of the cup, become reduced, and in the latest form are quite short. In the three lower diagrams the change in shape of the fossula—a space due to the shortness of the septum at the bottom of each diagram—should also be noted.

The smaller diagrams represent the younger stages of the corals they accompany; it will be noticed that each closely resembles the adult of the form *below*. This is an example of recapitulation, the adult stage of an organism being repeated as a young stage of its descendant.

---

206. *British Museum (Natural History).*

Piltdown Man and Rhodesian Man.

The skull discovered in a river gravel at Piltdown in Sussex is the oldest human skull known; it was described in 1913 by the late Mr. Charles Dawson and Sir Arthur Smith Woodward, F.R.S. The skull is chiefly remarkable for the great thickness of the bone, but the lower jaw is almost precisely that of an ape, with a very retreating chin and with the lower canine teeth interlocking with the upper canines in the true ape-fashion.

The skull found in 1921 in a cave at the Broken Hill Mine, Northern Rhodesia, is noteworthy for the immense size of the bony face, surmounted by brow ridges stronger than in any other human skull and recalling those of a gorilla.

The exhibits include casts of these two skulls, made and exhibited by Mr. F. O. Barlow, and, for comparison, skulls of a modern man and of an ape.

---

207. *Prof. J. P. Hill, F.R.S.*

The Egg-Laying Mammals.

The Monotremes, or egg-laying mammals of Australia, Tasmania and New Guinea, are by far the most primitive living mammals, and constitute a connecting link with our reptilian ancestors. The Platypus (*Ornithorhynchus*) has a soft furry coat, webbed feet, and a snout like a duck's bill; it inhabits pools and quiet reaches of rivers, and makes a long burrow in the bank, with side chambers in which the eggs are laid. The Spiny Ant-eaters (*Echidna* and *Tachyglossus*) are terrestrial animals protected by sharp spines.

The eggs generally number two in *Ornithorhynchus;* they are oval, about two-thirds of an inch long, and provided with a tough shell; when laid, the mother lies on or round them to keep them warm. In *Echidna* the single egg is incubated in a pouch on the abdomen of the mother.

In their development the Monotremes show a remarkable mixture of reptilian and mammalian features, and thus afford strong evidence of the derivation of mammals from reptilian ancestors. The earliest developmental process, segmentation or cleavage, undergone before the egg is laid, is of the partial type characteristic of reptiles. During incubation the embryo lives on

nutritive material contained in the yolk-sac and breathes by means of a membranous sac rich in blood vessels applied to the inside of the porous egg-shell. At hatching, the shell is broken by means of a conical projection on the snout, aided by an "egg-tooth" just behind the middle of the upper lip. So far the development has been essentially reptilian in character, but the newly hatched Monotreme, although it exhibits reptilian features such as an up-turned nose or "shell-breaker," an egg-tooth, and a remnant of the yolk-sac, is mammalian in its general form and structure. The helpless, naked little creature (about two-thirds of an inch long in *Ornithorhynchus*, half an inch in *Echidna*) subsists on milk secreted by the mammary glands of the mother, and gradually increases in size and grows more like its parents.

---

208. *Dr. F. A. E. Crew.*

Sex-Reversal in the Common Fowl.

Assumption by old hens of male plumage, spurs, etc., is known to be associated with disease of the ovaries. About forty old hens that showed signs of such disease were observed for two years; at the end of this time all had assumed the male plumage to a greater or less extent. Most remained sexually indifferent, but one, a Buff Orpington, paid ardent attention to hens and crowed lustily; it was mated with a virginal hen of the same race, which three months later produced fertile eggs from which two chicks were hatched. These chicks grew up; they were quite good Buff Orpingtons, one a cock, the other a hen; chickens have been obtained from them.

Examination of the hen that had behaved as a cock showed that the ovaries were destroyed by tubercular disease, and that small testes were present. Examination of other birds showed that they were at different stages in sex-reversal. The formation of the spermatic tissue appears to be accomplished by a thickening of the epithelium covering the surface of the ovary, a proliferation inwards from this epithelium of columns of cells, and the enlargement of these cells to form tubules of a testicular character.

The exhibit consists of photographs of hens and photo-micrographs of the reproductive glands.

---

209. *Prof. R. C. Punnett, F.R.S.*

Synthesis of a White Breed of Fowls from Two Coloured Breeds.

A cross between a Silver Campine cock and a Chamois Campine hen gives "ghost barred" white birds of both sexes. Such F.1 birds bred together give rise to an F.2 generation comprising five different sorts of birds, namely, ghost-barred whites similar to the F.1 birds, silver and chamois birds similar to the two original parental varieties, gold Campine and pure white. Certain of these whites are fixed and may be used to produce a pure white breed of Campines.

---

210. *British Museum (Natural History).* **Zoology.**

Evolution of the Elephant.

The earliest member of the Proboscidea is *Moeritherium*, discovered by the late Dr. C. W. Andrews, F.R.S., in the Upper Eocene beds of the Fayûm in Egypt; this was an animal about the size of a tapir, with a skull very like that of other primitive hoofed animals.

Palaeomastodon, from the lower Oligocene of the Fayûm, also discovered by Dr. Andrews, was larger than *Moeritherium* and in other characters approached the Miocene *Tetrabelodon*, which was very similar to an elephant, but had a long lower jaw with a pair of incisors at the end, used for grubbing in the earth. The later changes leading to the modern elephants were the reduction of the chin, loss of the lower incisors, and increase in size and complication of the cheek-teeth.

Casts of skulls of *Moeritherium* and *Palaeomastodon*, made and exhibited by Mr. F. O. Barlow, may be compared with the skull of an Indian elephant. The increase in size, the development of the tusks, the increase in number of the ridges on the molar teeth, and the shifting back of the nasal opening (corresponding to the development of the trunk), are features to which attention may be directed.

BOTANY.

211. *Department of Botany, British Museum (Dr. A. B. Rendle, F.R.S., and Mr. R. D'O. Good).* **Botany.**

Colour in Plants: its Preservation or Replacement for Purposes of Exhibition.

Two objects have to be achieved in the successful preservation of botanical specimens for exhibition purposes—namely, the preservation of the original form and the preservation or reproduction of the original colour. Last year's exhibit dealt more particularly with the former of these: this year's exhibit is designed especially to illustrate the latter.

The colours of healthy plants living under normal conditions are due to the presence within the living tissue of certain highly coloured organic pigments. These pigments are of six kinds and are found either included in colour-bearing granules (chromoplasts) within the protpolasm of the cell or in solution in the liquid contents of the cell (cell-sap). Under certain conditions a degree of colour may be due to substances other than true pigments, as is often the case with plants which contain tannins, but such substances are not considered in this exhibit. The pigments illustrated all play a definite rôle in the physiology of the plant and are all more or less essential to the performance of its vital processes.

The substances concerned fall under the following six heads :—

(i) *Chlorophylls.*

Green chromoplast pigments found in almost every part of the plant but most abundantly in the leaf. The green pigments of the leaf consist of two closely related and similar complex carbon compounds containing a small proportion of the element magnesium and having the chemical formulæ $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$. It is interesting to note that there is a considerable similarity in structure and reactions between chlorophyll and hæmoglobin, the red colouring matter of mammalian blood. To the plant chlorophyll is of vital necessity, since it is only when this substance is present that the organism is able to manufacture its own food out of inorganic materials.

(ii) *Carotins.*

Yellow, orange or red chromoplast-pigments. These are most often found associated with chlorophyll in the green leaf, but they also occur alone in many plant-organs, to which they frequently give a bright colour, *e.g.*, the root of the carrot and many yellow flowers and fruits. There are three principal carotin pigments: carotin itself, xanthophyll and fucoxanthin. The first is a hydrocarbon with the formula $C_{10}H_{56}$. The second, usually associated with the first, has the formula $C_{40}H_{56}O_2$, and the third, which is only found in the brown seaweeds, has the constitution $C_{40}H_{54}O_6$.

(iii) *Anthocyans.*

Blue, purple or crimson cell-sap pigments. Very widely distributed in plants and the cause of nearly all the blue, purple and crimson colours in flowers, fruits, leaves and stems. They are often abundant in young unfolding plant-organs and in leaves and stems at the end of the growing season (autumn-tints). They occur chiefly as the glucosides of certain complex aromatic compounds derived from benzo-pyrilium.

(iv) *Anthoxanthins* (*Flavones*).

Yellow cell-sap pigments. These are of common occurrence in many plant-organs, especially flowers, but usually in such dilute solutions that their colour is not striking. When present in greater abundance, they give brilliant colours as is the case in the yellow varieties of the garden snapdragon. The yellow dyes of Dyer's weed and Dyer's greenweed are also due to anthoxanthins. They are found as the glucosides of certain complex aromatic carbon compounds derived from flavone and xanthone.

(v) *Phycoerythrin.*

A red chromoplast-pigment. It is found almost exclusively in the red seaweeds, associated with chlorophyll, and gives their characteristic colour. Its chemical constitution is uncertain, but it is possibly a colloidal substance allied to the proteins.

(vi) *Phycocyan.*

A blue-purple chromoplast-pigment. This also is found associated with chlorophyll in certain seaweeds but is much less common than phycoerythrin. It is said to have a similar constitution.

Botany.

The general form of botanical specimens can be preserved in two ways—either by drying in air or sand, or by immersion in preservative liquids, of which the most convenient for ordinary use are formalin (4 per cent. solution of formaldehyde) or colourless commercial spirit. In this latter " wet " method, loss of colour is usually rapid and there is no satisfactory way of preventing it. In the " dry " method a considerable degree of colour-retention can be achieved by suitable means.

Colour loss may be due to two processes:—(a) Upon the death of coloured plant-tissues the contained pigments are soon decomposed by the action of substances, called enzymes, in the plants themselves. This action is facilitated by the presence of moisture. (b) In the absence of enzyme action the pigments are more slowly decomposed by the action of light, and, more rarely, of air. These processes affect different specimens in very different ways. The colours of some are extremely fugitive, while in others they are almost permanent, even in formalin or alcohol.

By rapid drying under warm conditions—either by pressure between layers of absorptive material or in warm, dry, silver-sand—enzyme action is partially or entirely prevented, and the specimens retain their natural colour for a period depending upon the resistance of these pigments to the action of light and air. In certain cases this period may be almost indefinite. A series of specimens is shown to illustrate colour-retention under dry conditions.

In the " wet " method of preservation enzyme action is not so easily prevented, light cannot be so completely excluded, and the pigments are often affected by the liquid media used. In these circumstances loss of colour occurs rapidly and a more perfect preservation of form is achieved at the sacrifice of colour. Some pigments seem to be but little affected if formalin is used, but these are few. In some cases the action of the preserving fluid can be prevented by first dipping the specimen into melted gelatine. This is then allowed to harden, and the specimen becomes covered by a thin, translucent, impervious coating. One section of the exhibit illustrates the effect of " wet " preservation upon natural colour.

As an alternative to their preservation, the natural colours of plants can often be imitated and replaced by chemical means. Such a method is particularly effective and valuable in the case of the green pigments (chlorophylls). The process is performed in the following way:—A saturated solution of copper acetate in glacial acetic acid is diluted to four times its original volume. It is then brought to the boil and the specimen is immersed in it. The period of immersion varies with the nature of the subject from a few minutes to half an hour in the case of very fleshy plants. During the immersion a complex chemical change takes place, in the course of which the magnesium in the chlorophyll is replaced by copper and a copper-chlorophyll compound is formed. This compound has the same colour as the original chlorophyll and is not decomposed by the action of formalin or light. Specimens treated by this " greening " process can afterwards be preserved either in formalin or by drying in the usual way.

Certain of the other plant-pigments can be imitated by means of suitably coloured dyes. This method is particularly effective in

Botany.

the case of seaweeds. The specimens so stained can be preserved either dry or in a fluid which does not dissolve the dye. The last section of the exhibit illustrates these "greening" and dyeing processes.

---

212. *Mr. H. Hamshaw Thomas.*

The Earliest Known Fruit-Bearing Plants and their Relation to the Problem of the Evolution of the Flowering Plants.

The origin and early evolution of the flowering plants is one of the most baffling problems of botany. Plants of this type form the greater part of the present vegetation of the world and provide the main source of vegetable food for man and animals. They are extremely varied in character and more than 135,000 species have been recognised. Their flowers exhibit innumerable forms, but they all agree in the possession of ovaries which give rise to fruits containing seeds, and in having stamens of a characteristic form in which pollen-grains are produced.

The record of the rocks seems to show that this class originated at a relatively late period in the earth's history, and that they quickly spread over the whole world, evolving myriads of new types with great rapidity when compared with other groups of plants. Charles Darwin regarded this as one of the most difficult evolutionary problems which had to be solved, and referred to it as "an abominable mystery."

In spite of a long-continued and careful search in the rocks, no definite traces of flowering plants have been found in the strata of pre-Cretaceous age, while many of the leaves of the earliest fossil flowering plants are not far different from the leaves of their modern representatives. The theory of evolution indicates that they must have sprung from some pre-existing group, but the practical difficulty is to find evidence of the existence of such a group. The exhibitor has recently found in the Middle Jurassic (the age of many giant fossil reptiles) rocks, exposed on the shore near Scarborough, in Yorkshire, the remains of a new group of plants which may be regarded as allied to the hypothetical plant-type from which our flowering plants have evolved.

This group—which is named the Caytoniales—included plants which possessed fruits containing seeds, and stamens containing pollen-grains, which are very similar to those characterising the modern flowering plants, but they had no definite flowers. Their leaves were also simpler in structure than the leaves of most modern trees. Evidence has been obtained pointing to the existence of this group of plants in Greenland at a still earlier date (Rhaetic age), and probably it was very widely spread over the world at this period.

Although it may not be possible to regard the Caytoniales as the direct ancestors of the flowering plants, yet their characters and their wide distribution point to the existence of an important plant-type, which possessed the most essential organs which

go to form a flower, at a period prior to the appearance of the first definite flowering plants. This discovery may lead to the gradual elucidation of the great problem. **Botany.**

Apart from their theoretical aspect these plants possess some interest, for they are the earliest known types in which were formed small fleshy fruits containing hard seeds, somewhat like those of the currant grape.

The exhibit illustrates the problem referred to above. It includes an autograph letter on the subject written to Darwin by the Marquis de Saporta, one of the most eminent palæobotanists of his day; diagrams showing the rapid increase in the numbers of fossil flowering plants in the successive periods after their appearance; and specimens showing the great similarity in form between early fossil leaves of flowering plants and those of to-day. Specimens of fruits and seeds of the Caytoniales from Yorkshire are shown, together with drawings and photographs illustrating their structure. A piece of rock containing parts of the stamens is shown, and a photograph and drawings of the winged pollen-grains which they produced. Specimens of the leaves which probably belonged to these plants are also exhibited.

---

213. *Mr. H. Hamshaw Thomas.*

Photographs illustrating the Use of Aerial Photography in the Study of Vegetation.

Aerial photography provides valuable assistance in the study of the distribution of vegetation and of its relation to the soil and topography. Vegetation characterised by different plant-types can generally be clearly recognised in photographs taken from above, and its features and extent can be noted in a way which could scarcely be excelled by many months of survey-work on the ground. This method of work is of special interest and importance in the study of the development of a plant-covering on the newly exposed sand or mud of coastal lands.

The examples exhibited include part of an aerial survey of Blakeney Point on the Norfolk coast, in which the distribution of the plants on the sand-dunes, shingle-bank, and mud-flats can be seen; photographs taken at various points on the ground are added for comparison.

Other examples show aerial views of different vegetation-types, and illustrate the way in which the distribution of desert scrub, and of woodlands, etc., can be determined. The distribution of riverside woods or thickets in the Jordan valley is shown by three views taken in different directions. Other photographs show European woodlands and fields in winter and summer.

Botany.

214. *Prof. V. H. Blackman, F.R.S.*

Plant Physiology.

(A) Apparatus for Determining the Rate of Assimilation of Green Leaves.

The leaf is placed in a glass jar containing air enriched with carbon-dioxide, the amount of this gas absorbed being determined by the change in colour of a solution. By means of the water vacuum-pump and mercury valves the air is made to circulate through the apparatus; in its passage it bubbles through the coloured solution and returns again to the jar. As assimilation proceeds the carbon-dioxide decreases in amount and the colour of the dye changes from yellowish-blue to purple. From this change in colour the amount of the gas absorbed by the leaf can be determined.

(B) Apparatus to Determine the Amount of Water lost by a Potted Plant in the Process of Transpiration.

The plant is placed on one pan of a balance and counterpoised by weights in the other pan. As the plant loses water the pan supporting it rises and so makes electrical contact between two wires and the mercury in the cup attached to the pan. An electrical circuit is thus closed, as a result of which the magnet pulls away the cup through which the slow stream of water from the reservoir has been flowing to waste. The water now drops into the pot, and the left-hand pan gradually falls again. This brings about the rise of the right-hand pan, resulting in the closing of another electrical circuit seen on that side of the balance; the cup is then pushed forward again and the water once more runs to waste. The cycle is started again by the further loss of water from the plant.

Every time the left-hand electrical circuit is closed, a current is sent through the magnet actuating the recording pan and a mark is made on the revolving drum. A continuous record of water lost by the plant can thus be obtained for a period of twenty-four hours without any attention, and at the same time the moisture of the soil is kept nearly constant.

(C) Apparatus to Record Electrically the Rate of Growth of a Plant.

The top of the stem is attached by a thread to a spring under slight tension. Elongation of the stem allows the spring to rise and to make electrical contact above. The current passing causes the toothed rod bearing the spring to rise about 1/200 in. As a result the spring is again extended and contact is broken. Each time contact is made a record appears on the revolving drum.

DEMONSTRATION.

---

215. *Prof. P. Groom, F.R.S.* **Botany.**

Cultures of Fungi causing Decay of Timber in Houses.

The cultures include *Merulius lacrymans, Merulius corium, Merulius tremellosus, Coniophora cerebella, Polyporus destructor* and others.

Specimens of wood from houses attacked by some of these species are shown.

Some of the fungi (*e.g., Coniophora cerebella*) can attack only wood that is thoroughly damp, as they cannot manufacture water sufficient for their growth; others (*e.g., Merulius lacrymans*), when once established, can attack the driest wood, as they can render this moist by means of the water that they produce and excrete. All the fungi exhibited grow inside timber, but only certain of them (*e.g., Merulius lacrymans, Coniophora cerebella*) can also advance over or through other materials (*e.g.*, brick walls), and can thus cause rapid destruction of the woodwork of a building.

PHYSIOLOGY.

216. *Dr. E. D. Adrian, F.R.S.* **Physiology.**

Electrical Apparatus for Research in Physiology.

Electrical measurements play a large part in physiology, for much of our knowledge about the tissues concerned with movement (the muscles and the nervous system) is derived from observations of the electrical effects which accompany activity. The currents which have to be measured are small and are of very brief duration; for example, the "action current" which accompanies a nervous impulse does not last for more than a few thousandths of a second.

Special instruments are needed to give a faithful record of these brief currents, and one of the most successful is Einthoven's string galvanometer. In this, the moving part is a silvered glass thread stretched in a magnetic field and so light in weight that it can follow the most rapid changes with a minimum of distortion. It is shown arranged for recording photographically the currents produced by the beating heart, the limbs of the subject acting as leads from the heart to the galvanometer. The study of these records in patients with heart disease has been of great importance to the physician. Photographs are also shown of the action current in a nerve and of those developed in the muscles of the forearm when the hand is tightly clenched.

Electric currents are also used by the physiologist for stimulating muscles and nerves to activity, and instruments of great precision are needed to control the duration of the stimulus or to send in two stimuli in rapid succession. The mechanical contact breaker, designed by Keith Lucas, strikes open two switches at an interval which can be varied from 1/5000 to 1/50 sec. It is used for determining the "chronaxie" and the "refractory period" of nerves and muscles.

Physiology.

Another field in which electrical methods have come to play a large part is in the determination of the acidity or hydrogen-ion concentration (P_H) of the various fluids of the body. The smallest change in reaction may have far-reaching effects on the organism, and the most delicate method of measuring such changes is by means of the hydrogen electrode. The E.M.F. from the electrode is balanced against a potentiometer and standard cell.

The Electro-cardiograph and other apparatus by the CAMBRIDGE INSTRUMENT CO., LTD.

DEMONSTRATION.

---

217. *Prof. E. P. Cathcart, F.R.S.*

The Measurement of the Energy expended during Movement.

(A) The Bicycle Ergometer.

This apparatus permits of the accurate investigation of the energy of expenditure during bicycling, and more particularly the determination of the mechanical efficiency with which the work is done. It consists of an ordinary bicycle frame carrying a rear wheel which is in the form of a heavy copper disc. This disc, when the subject pedals, is made to rotate between the poles of a powerful electro-magnet. By varying the current in the magnet, varying resistance to the passage of the disc through the field may be induced. The amount of work done in kilogrammetres can be determined by a simple calculation.

(B) Bomb Calorimeter.

This is the apparatus which is used to determine the heat (or caloric) value of different foodstuffs. The foodstuff, squeezed into pellet form, is placed in the bomb, and the bomb, after closure, is filled with oxygen under pressure. The bomb is next placed into a known volume of water, the temperature of which is very carefully determined. When the water temperature is constant, the pellet of food material in the bomb is fired by means of electricity and is rapidly burnt in the oxygen-rich atmosphere. When it burns, the heat given off is taken up by the water, with a rise in temperature as a result. The amount of the rise is carefully determined, and from this and the volume of water warmed, the heat of combustion of the foodstuff may be determined.

(C) Douglas Bag.

This is the apparatus used for the indirect determination of the energy expenditure of a human being during the performance of any kind of work, When the subject, carrying the bag on his back, is using the mouthpiece, all his expired air is collected in the bag during any determined period. The duration of the experiment depends on (i) the size of the bag and (ii) the nature of the work done.

(D) Haldane Gas Analysis Apparatus.

A sample of the expired air is collected from the Douglas bag, and its content in carbon dioxide and oxygen is determined by analysis in this apparatus. A measured amount of air is taken into the graduated burette. It is then passed into a solution of potassium hydroxide to remove the carbon-dioxide, and the resultant diminution in volume is measured in the burette. It is next passed into an alkaline pyrogallate solution to remove the oxygen and is again measured. In this way the carbon-dioxide and oxygen content of the sample taken are determined. As the total volume of air expired is known, it is easy to calculate the total amount of carbon-dioxide expired and of oxygen used during a given period.

Apparatus in (B), (C) and (D) by MESSRS. BAIRD AND TATLOCK (LONDON), LTD.

DEMONSTRATION.

---

218. *Prof. D. T. Harris.*

The Physiological Action of Light.

An assembly of apparatus for the determination of the action of light upon the affinity of blood for oxygen is shown. The two containers are bottles of identical size and shape made of quartz, because this material is transparent to almost all types of radiations, including the ultra-violet. One quartz bottle contains a measured quantity of blood and the second bottle contains exactly the same volume of a saline solution; the latter bottle is the control bottle and is subjected to precisely the same conditions as the bottle containing the blood. These two bottles are kept at a constant temperature of 37° C. in an electrically-controlled thermostat; in this way the effect of heat can be eliminated. The two bottles are connected by very thick india-rubber tubing to a **U**-tube and a graduated burette arranged according to the compensating device of Dr. J. S. Haldane, F.R.S.

The mercury-vapour lamp is used as a source of light and the radiations transmitted through its quartz bulb pass through the quartz window in the side of the bath; the heat rays are trapped by the distilled water of the bath and thus only the light rays (visible and ultra-violet) reach the blood. Continuous agitation of the bottles by means of an electro-motor causes the blood to be spread out in a thin film, thus allowing a larger surface of blood to be presented to the light and to enable gas exchange between the blood and air in the bottle to occur more rapidly.

The bottle is first covered with a dark opaque jacket and fresh blood introduced and suitably diluted. Time is given for the

Physiology.

attainment of equilibrium between the oxygen in the blood and the oxygen in the air above it and the graduated burette is then read off. The jacket is now removed, the light switched on, and the change of reading due to the light is observed. Finally, the light is switched off, the dark jacket replaced, and return to the original state occurs.

DEMONSTRATION.

---

219. *Dr. E. H. J. Schuster.*

A New Respiration Pump.

The object of this pump is to keep animals alive by artificial respiration while under experiment. It can be used successfully with an animal, the brain of which has been removed and even the whole head cut off. The pump is provided with two barrels each connected with two nozzles; by means of mechanically operated valves, each barrel discharges air through one nozzle and takes it in through the other. In the simplest application of the pump, the delivery nozzle of one barrel and the suction nozzle of the other are connected by rubber tubing with the windpipe of the animal, the other two nozzles being left open. On the delivery stroke, air is blown by one barrel into the lungs of the animal, while the other barrel empties itself into the surrounding atmosphere. On the suction stroke, clean air is drawn into the first barrel, and used air from the lungs of the animal into the second. Respiration pumps with two barrels working on this general principle have been used successfully for many years.

The chief novelty of the pump exhibited consists in the fact that it is possible to vary the distance of the crank pin from the centre, and so the amount of air delivered at each stroke, while the pump is running. This amount can thus be accurately adjusted to the needs of the experiment. Another novelty is the provision of a simple attachment by which the pump may be converted into a perfusion pump—that is to say, used to maintain a circulation of blood or other fluid through an organ which has been removed from the body of an animal. The organ can be kept alive in this way for many hours, and experiments made on it—for example, by introducing various drugs their effects may be studied. Finally, the pump is by far the most compact yet made.

Apparatus by MESSRS. BAIRD AND TATLOCK (LONDON), LTD.

DEMONSTRATION.

---

220. *Mr. N. K. Adam.* **Physiology.**

Apparatus for the Study of Thin Surface Films on Water.

A development of the apparatus used by Langmuir (1917), who first applied this method to the study of surface films. The essentials are: (1) a shallow trough filled with water; (2) scale for measuring length of the films; (3) glass strips for sweeping the surface clean from impurities; (4) a special balance for measuring the force of compression on a float bounding one end of the films; and (5) air jets directed on the gaps between the ends of the float and sides of the trough, to prevent escape of the films.

In use, the surface is first swept clean, and a known quantity of the substance to be investigated immediately put on. Measurements of the areas occupied under various compressions are made, at different temperatures. The structure of the film is deduced from the compression-area curves.

The films of fatty substances on water are found to be always one molecule thick. There are two main types, the condensed and the expanded films. Condensed films pass into expanded films when the temperature is raised above a definite point. In the condensed films the molecules are as closely packed as in solids or liquids, and the films may be either solid or liquid. The molecules are arranged vertically, perpendicular to the water surface. Their shapes may be found from the films, to some extent, and are in good agreement with the structural formulae of organic chemistry; the dimensions found agree with the results of X-ray analysis of crystals. In the expanded films the molecules are not closely packed.

While the principal application of this method is to the problem of exploring the fields of force of molecules, these films are the simplest kind of membrane. Leathes has found that the influence of lecithin and cholesterol on these films is closely parallel to their action on red blood corpuscles. Gorter (*J. Expt. Med.*, vol. 41, p. 4, 1925) has employed this method for estimating very small amounts of fat.

DEMONSTRATION.

---

221. *Dr. H. Hartridge and Mr. F. J. W. Roughton.*

Apparatus used for Measuring the Velocity of Rapid Chemical Reactions.

In order to study the velocity of reaction between any two fluids, the latter are placed in separate bottles and are driven from these through leads, which deliver by means of fine jets into a small mixing chamber. Here the two fluids meet one another, mix (in less than one thousandth of a second) and then travel with uniform velocity down an observation tube fixed to the mixing chamber. Observation at different points of the latter, by means of the spectroscope (or by other suitable physical methods) gives the chemical composition of the fluid at different intervals of time

Physiology.

after mixture. The time can be calculated at once from a knowledge of the bore of the tube and the volume of fluid passing in a given time along the observation tube. In this way the time course of suitable chemical reactions can be readily followed. The apparatus has so far been chiefly used for measuring the rate at which oxygen combines with, and dissociates from, the blood pigment hæmoglobin.

The method would appear to be applicable to the study of many other chemical reactions and physico-chemical processes. Reactions half completed in times varying from $\frac{1}{1000}$ to 5 seconds have been satisfactorily investigated by its use.

DEMONSTRATION.

222. *Dr. H. Hartridge.*

The Reversion Spectroscope.

This instrument is used for determining accurately the position of absorption bands in the visible spectrum. The absorption spectrum of the solution under examination is duplicated, one spectrum being reversed and situated above the other. By means of a suitable mechanism, one of the spectra can be shifted bodily so that different parts of the spectra can be made to coincide in turn.

When absorption spectra are being investigated, corresponding bands are brought into accurate alignment. When two pigments with overlapping bands are present in a solution, it is possible to calculate the relative proportions of the two pigments present, if the position of the resultant absorption band has been accurately measured as above. The apparatus was originally designed for estimating the ratio of oxygen to carbon monoxide in blood, but has since been applied to a number of other purposes.

DEMONSTRATION.

223. *Dr. H. Hartridge and Mr. C. F. Williams.*

A Self-contained Microscope Illuminator.

In this illuminator, a small electric lamp contained in a metal box forms the source of light. For diffusing the light, a slab of opal glass is mounted in the lid of the box. An iris diaphragm is mounted above this for controlling the area of illumination. The box is attached to the tail-piece of the microscope in place of the mirror. A substage condenser focusses an image of the aperture in the iris diaphragm on to the specimen, which lies on the stage. The principal advantage of the illuminator is that when once it has been adjusted to the optical axis of the microscope, it remains in adjustment no matter where the microscope is placed or at what angle it is tilted.

DEMONSTRATION.

224. *Portraits of Eminent Biologists.*

Photographs are exhibited of :—

Charles Darwin (1809–1882).
Thomas Henry Huxley (1825-1895).
Alfred Russel Wallace (1823–1913).
Francis Galton (1822–1911).
Charles Lyell (1797–1875).
Joseph Dalton Hooker (1817–1911).
William Harvey (1578–1657).
Walter Holbrook Gaskell (1847–1914).
Lord Lister (1827–1912).

---

225. *Charter Book of the Royal Society.*

Facsimile Reproduction of the Signatures.

"Soon after the incorporation of the Society a folio volume was prepared of leaves of finest vellum. It is bound in crimson velvet with gilt clasps and corners, having on one side a gift plate bearing the shield of the Society and on the other the eagle crest. Into this volume the Charters were transcribed, and it is thus known as the 'Charter-book.' After the Charters and Statutes follow the signatures of the Fellows, commencing with that of the King, and on the same page, those of the Duke of York (afterwards James II.), George (Prince of Denmark and Consort of Queen Anne) and 'Rupert, Fellow.' In the Journal-book, under date January 11th, 1664/5, it is recorded that 'the Charter-book of the Society was produced wherein His Majesty had written himself CHARLES R., FOUNDER: and His Highness the Duke of York, James, Fellow; the Duke of Albemarle also having entered his name at the same time.' Pepys relates that being at Whitehall, 'I saw the Royal Society bring their new book wherein is nobly writ their Charters and Laws, and comes to be signed by the Duke as a Fellow and all the Fellows' hands are to be entered there, and lie as a monument; and the King hath put his with the word Founder.' Prince Rupert, who was elected in March, 1664, took much interest in some branches of Science, and in the work of the Society. Prince George, on November 30th, 1704, 'was unanimously chosen a member of the Society,' and, on December 13th following, wrote his name in the book. After the Royal signatures come the autographs of the Fellows who have been admitted from that date down to the present day. At the time of his admission each Fellow first signs his name in the Charter-book beneath the declaration that he will endeavour to promote the good of the Society and obey its rules, and he then shakes hands with the President, who declares him to be a duly elected Fellow of the Society."

From the *Record of the Royal Society of London*, 1912.

The volume exhibited contains a series of facsimile reproductions of the pages bearing the signatures.

SCIENTIFIC FILMS.

A programme of scientific films is shown in the exhibition galleries, with a miniature projector, the Kodascope, using safety film. Certain of the films have been specially taken; others have been copied from existing films of standard size, by arrangement with the owners, as under :—

"X-Rays. A Film showing the Principles of X-Rays and the Essential Operations in the Manufacture of Coolidge Tubes for X-Ray Work." *British Thomson-Houston Co., Ltd.*

"Wireless Direction-Finding for the Air Services." *Marconi's Wireless Telegraph Co., Ltd.*

"The European Corn Borer." *Provincial Government of Ontario, Canada.*

A number of films of scientific interest by the *General Electric Co., Ltd., Messrs. Kodak, Ltd.*, and others.

Examples are also shown of the work of Mr. W. Heape, F.R.S., and Mr. H. B. Grylls on high-speed cinematography. The originals of these films have been taken on the Heape and Grylls Rapid Cinema Machine.

The machine is capable of taking stereoscopic pairs of photographs at any rate from 500 to 5,000 per second, on standard film. At full speed, the exposure of each portion of film is $\frac{1}{75000}$ second.

The principle employed is that the portion of film being exposed and the lens forming the image move together, so that there is no motion of the image relative to the film. Exposure is made through a narrow slit of variable width.

Those films which have been reduced from the standard size have been copied by MESSRS. KODAK, LTD., who have also kindly provided the Kodascope projector.

INDEX TO EXHIBITORS.

(*The Numbers refer to pages*).

INDEX TO FIRMS PROVIDING APPARATUS.

(The Numbers refer to pages.)

P 81—18/cc H & S, Ltd. Gp. 34